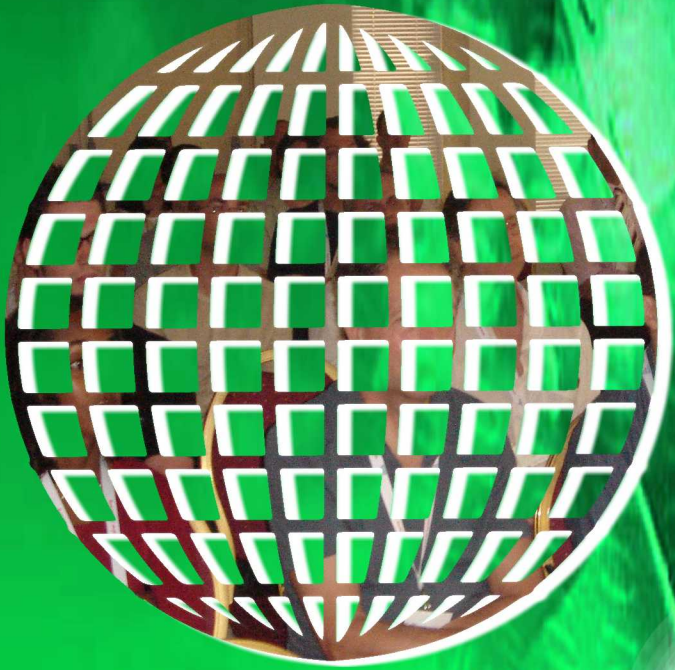


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Move Better with tripzoom

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Abstract—The increase of urban traffic confronts individuals and transport authorities with new challenges regarding traffic management, personal mobility, sustainability, or economic efficiency. Existing resources cannot be arbitrarily extended without negative effects on pollution, costs, or quality of living and have to be used more efficiently. The SUNSET (Sustainable Social Network Services for Transport) project aims to improve this situation on a city-wide level by motivating users on a personal level to change their mobility behavior. To make personal mobility more sustainable, flexible, and rewarding for users, SUNSET combines mobility data and patterns from mobile sensing, a dynamic incentive system, and feedback from social networks. This paper describes how the tripzoom application implements this conceptual approach, discusses critical issues and outlines the forthcoming living lab evaluation in several European cities.

Keywords—sustainable traffic; mobile mobility; mobile sensing; incentives; social networks; living labs

I. MOBILE MOBILITY

Urban environments provide many different challenges for transport and traffic authorities regarding sustainability (e.g., CO₂, air pollution), accessibility (e.g., congestion) or economic efficiency [1][2]. Existing traffic networks often operate at their limits and need to be extended or improved to meet the increasing mobility needs of an increasing number of people. Urban mobility management has to use existing resources more efficiently to improve personal mobility and to reduce congestion, accidents, and pollution at the same time. It also has to cope with conflicting interests. Road authorities want to optimize traffic to enhance accessibility and sustainability, while individual people want to move comfortably and save time and money.

Some approaches try to solve the challenges of urban traffic by extending the capacities of existing infrastructures and transport modalities. Other, more human-centered approaches target individual travelers and encourage them to change their travel behavior instead. They address personal goals like healthy living, flexibility, or sustainability, motivate travelers on a personal level to improve these goals and thus achieve system goals like reduced congestion,

reduced air pollution or improved safety. Examples for novel mobility concepts that appeal to individual travelers and urban transport authorities alike are services for ride sharing (e.g., Avego [3]) car sharing (e.g., Whipcar [4], ZipCar [5] or GreenWheels [6]) or bike rental (e.g., DB Call-a-Bike [7], Velib [8] or Yokohama Bay Bike [9]) that show up in a growing number of cities all over the world.

Other solutions take advantage of mobile devices and applications to make travelling, transport and commuting smarter, more flexible and more beneficial for individual users. Mobile devices allow users to easily retrieve and communicate traffic-related information. They feature technologies like GPS or accelerometers to provide location data, suggest routes or detect user mobility. Mobile devices can also be highly personalized, context-aware [10] and persuasive [11]. They can influence the travel behavior of their owners by stimulating them in a personalized way and by providing incentives that match their motivations and preferences in the right place and at the right time.

The European FP7 project “Sustainable Social Network Services for Transport” (SUNSET) [12] is developing the tripzoom application [13] to investigate *mobile mobility* – solutions for personal mobility based on mobile devices and applications. With the tripzoom app (Fig. 1), SUNSET combines three means to improve personal mobility:

- **Personal Mobility Monitoring:** SUNSET uses mobile devices and their sensing capabilities to create individual mobility profiles with details about mobility patterns and transport modalities. These profiles allow users to zoom in on individual trips, frequent travels and special places and to re-visit them in detail.
- **Incentives:** tripzoom builds on this mobility data to provide users with incentives that match their interests to motivate the use of alternative means of transport and to encourage more sustainable travel behavior.
- **Social Networking:** Users can share mobility data and incentives with the tripzoom-community and existing social networks to encourage further improvements of their mobility behavior. For example, the mobile tripzoom app visualizes individual performances regarding costs or CO₂ footprint and shows users how well they perform compared to the community (Fig. 1).

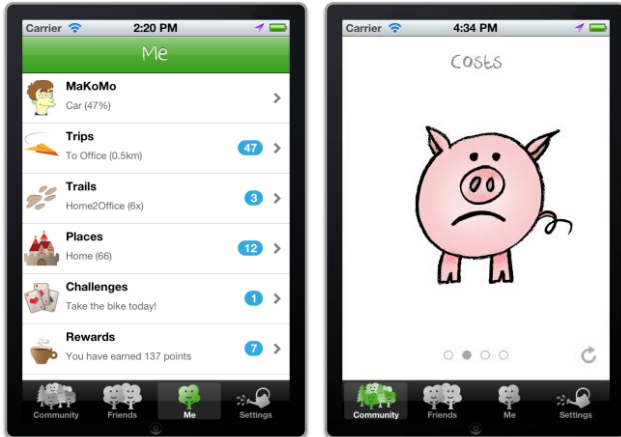


Figure 1. Mobile tripzoom app

The rest of this paper is organized as follows: After an overview of related work in Section II, Section III gives a general overview of the SUNSET approach and how it combines mobility monitoring, incentives and social networking to meet the challenges of modern traffic. Section IV describes the tripzoom application from a user's perspective, while Sections V and VI focus on technical details regarding system architecture and mobility sensing. Section VII concludes the paper with a discussion of our approach and an outlook to its evaluation in living labs in the cities of Enschede, Gothenburg and Leeds.

II. RELATED WORK

Our work on SUNSET and tripzoom is influenced by research on personal mobility, incentive mechanisms and living lab evaluations.

A. Personal Mobility

Most applications for personal mobility are related to information provisioning (e.g., Google Maps [14]) and mobility monitoring (e.g., [15][16][17][18]). Information can be provided to users via their mobile devices so that they can make better decisions regarding their trips. Such information involves trip planning, route guidance, and real-time traffic information (e.g., congestion, accidents).

Trip planning involves consulting maps, timetables, or online trip planners at home or relying on signs and fellow travelers on the road. As pointed out by Pitt et al. [19] the introduction of smartphones allows creating portable systems and multipurpose information appliances [20] that enable users to make sustainable decisions. With regard to personal mobility, smartphones make traffic related information, maps or timetables portable so that advanced tasks such as route planning can be done on the go. Mobile internet connections provide users with access to online trip planners and up-to-date traffic information, or allow them to arrange ride sharing [21] anywhere and at any time.

A common problem with most online trip planners is that they only accommodate single transport modalities. This makes the planner less useful for multi-modal trips, where

the traveler has to consult several planners. Examples for multi-modal trip planners include the DB Navigator [22] or ReseRobot [23], that support multi-modal trip planning with plane, train, bus, metro, ferry, tram and walking. However, driving by car or bicycle is not accommodated, excluding P+R as an option.

In-car navigation devices are becoming a standard feature of most new car models. The on-board unit typically uses GPS to acquire position data and then locates the car using the unit's map database. Although stand-alone units are common, they are not popular for use in non-car modes, as carrying the device along can be a burden for the traveler. Route guidance systems for mobile phones, such as Google Maps [14], can minimize the carriage burden. The map database is normally stored on the server and accessed via the mobile phone's internet connection. Therefore, the guidance is always based on the latest database, significantly reducing inconveniences caused by outdated information.

Mobility monitoring is realized by sensing movement data and matching it with the traffic infrastructure. The sensing component tracks the position of users via GPS and cellular information, while the matching component fits these movement data into the context of the map database and establishes the trip-level characteristics, including origin, destination, timing or routing. Pattern recognition techniques are then utilized to identify the mode of travel and the role of users (e.g., driver, passenger), and to recognize places of interest over time by learning from the user's past behavior. Examples for personal mobility monitoring include TravelWatcher [24] and IYOUIT [25], which also supports the sharing of personal experiences on the go.

Personalization is often overlooked in existing mobile mobility systems. Although certain personal settings are allowed for filtering information, the majority of information is provided in the same way to all users. Guidance and advices are constructed as if they apply universally, disregarding the travelers' individual needs and preferences. The digital innovation contest TravelHack 2011 [26] tried to solve this problem by building prototypes for digital mobility services that present travel-related information according to personal user settings [27]. This indicates the potential for future mobility systems that allow users to adjust systems to their needs and preferences. The personalized approach in SUNSET is another attempt to bridge this gap in mobile mobility services.

B. Incentives

Over the past decade, there has been a growing interest in using incentives in transport both in commercial applications and government implementations to achieve sustainable policy aims. A number of EU-countries have implemented a range of different initiatives, like travel planning, public transport marketing, travel awareness campaigns or mobility management. Initiatives that share a common desire to change travel behavior through persuasion are collected under the term "soft measures", while "hard measures" involve enforcement and legislation.

The design of incentives in transport policies has a history of being more ambitious than the technology will

allow. For a long time there has been a vision and a desire to be able to offer personalized, multi-modal travel planning support as an incentive, but the technology has not been available to make it happen. Policy initiatives like Smarter Choices in the UK [28] have tried to make travelling less costly and more beneficial, sustainable or healthier for individuals using personalized travel planning or mobility management. However, these initiatives have often been relatively time-consuming and costly for local authorities and municipalities to implement.

Another, very simple and persuasive measure for motivating particular travel behavior are “monetized” inducements like discounted tickets for using public transport at certain times, price reductions for bulk or annual purchases of tickets, or discounted rates for entrance to tourist and visitor attractions for those who arrive by train or bus. The Spitsmijden initiative [29] in the Netherlands experimented with offering cash incentives to drivers who changed their car travel patterns and avoided travelling on a congested section of highway during the peak times. While this approach was effective and resulted in a change in congestion, it was also criticized for potentially introducing inequity into transport policy implementations [30].

Theory and practical evidence indicate that peer pressure can be a very influential incentive for changing travel behavior [31]. Many policy makers and commercial interests are experimenting with social networks like Facebook, Twitter or Foursquare, to encourage and support sustainable behavior. Examples include car sharing (e.g., [4][5][6]) or bike rental (e.g., [7][8][9]). Social interactions like sharing, collaboration or competition can be amplified by social networks. Tapping into these social interactions, applications can provide new forms of engagement and stronger incentives.

Within the SUNSET project, a number of key approaches to incentive design have been explored [32]. We have found out that social network based sharing of incentives is attractive to some demographic groups but not all, that point-based incentives have to be exchangeable to generate loyalty, and that feedback is a mechanism that can be mainstreamed into everyday travel behavior. tripzoom offers the possibility of bringing together a number of novel and inventive concepts in incentive design through the use of dynamic, personalized, mobile social media to develop sustainable travel behavior.

C. Living Lab Evaluation

tripzoom will be evaluated in the real-life context of living labs [33] in Enschede, Gothenburg and Leeds. Eriksson et al. [34] define living labs as a research and development methodology whereby application enhancements, services, or products are created and validated in collaborative, multi-contextual empirical real-world settings. All stakeholders in a product, service or application participate directly in the development process. For SUNSET, this includes end-users and municipalities. Living lab experimentation strives for the same level of observation as is common in, for example, a usability lab, but in an organic, multi-contextual space. This means that customers participating in a living lab are

observed across many aspects of their lives, such as their roles as citizens, workers, at home or travelling. As such, living lab studies provide user feedback of high ecological validity. In SUNSET, the living labs will also collect high-value and real-life mobility data about their mobility behavior and patterns.

III. THE SUNSET APPROACH

The European FP7 research project SUNSET [12] takes a new approach to urban mobility management and personal mobility. For that purpose, its consortium contains partners from the complete value chain: providers of location-based services, mobile operators, local authorities, green mobility providers and research centers. The focus of SUNSET lies on urban mobility with a fine-grained maze of roads (as opposed to long-distance highways) and on commuters with good knowledge of their environment, but with limited overview of dynamic situations and routine behavior.

The SUNSET approach builds on mobile devices, personal mobility monitoring, a dynamic incentive system and information sharing over social networks to optimize mobility for individual users and to encourage the adoption of more flexible, sustainable and rewarding ways of traveling. This approach includes research on the recognition of individual mobility-patterns and transport modalities, the effects of different incentives to encourage users to change their travel behavior as well as mechanisms for building social communities and sharing travel-related information.

The SUNSET approach envisions an eco-system, in which individual travelers, communities, city authorities and 3rd party service providers interact with each other to optimize personal mobility (Fig. 2). Individual travelers provide the SUNSET eco-system with information about their preferences as well as mobility data about travels, transport modalities or places. In return, travelers can take advantage of personalized recommendations and services to optimize their personal mobility, share travel related information on social networks and receive incentives for improved travel behavior.

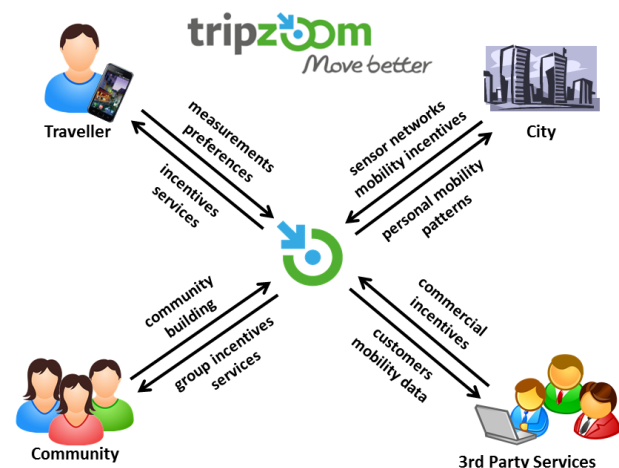


Figure 2. Stakeholders in the SUNSET eco-system

City authorities receive detailed, personal mobility data from travelers that are relevant for the assessment of current infrastructure use and future mobility needs. To optimize this data, cities can offer incentives to travelers. The information is targeted at individual travel behavior, and thus allows road authorities to fine-tune their transport policies and individual travelers to meet their personal objectives.

Third party service providers can tap into the wealth of mobility data to create novel services and offerings for travelers. They can also integrate with other parties and stakeholders through common incentive structures.

Communities, like participants of a car sharing system or employees of a company, can receive special group incentives and improve their networking.

A. Mobility Monitoring

To optimize personal mobility, individuals or groups need to be identified that are relevant for the optimization targets under consideration. Therefore, personal mobility sensing that uses mobile phones to track how travelers move, plays a fundamental role in the SUNSET system to gain profound insights into mobility behavior. One example is the detection of travel modalities, which combines orientation sensors, location data, and road network information to estimate the mode of transport in a reliable way. Other than systems that build on infrastructure data alone, e.g., on road sensors like NDW [35] in the Netherlands, SUNSET is able to target individual travelers to initiate a change in behavior in accordance with a global optimization of travel behavior across a whole city. For that purpose, the mobility behavior of the entire community or specific groups can be analyzed by aggregating mobility data across the respective users.

B. Incentives

One approach SUNSET employs to trigger behavior change is to provide incentives for specific target groups in specific mobility situations. Incentives may stem from all parties of the SUNSET ecosystem and may contain information about the current and future status of the transport infrastructure or about travel alternatives. To find the most effective types of incentives, we conducted an analysis of individual travel behavior [36]. This research implies that influential incentives should be based on the following aspects.

- **Time:** Travelers can save time, use it more efficiently, control it or plan trips in a better way.
- **Money:** Travelers can save money, for example with coupons or discounts on transportation tickets.
- **Information:** Travelers can receive useful (real-time, personalized) travel-related information about progress, accidents, alternative routes, etc.
- **(Social) Recognition:** Travelers can show (off) how green and healthy they are and give or receive feedback from other members of the community.

In SUNSET, incentives appear as challenges defined by a set of rules that users have to fulfill to earn a reward (e.g., take the bike 3 times a week instead of the car to get a discount on bike maintenance financed by a bicycle store).

SUNSET promotes an abstract point scheme to implement rewards and to facilitate the integration of 3rd party incentive offers. This includes the possibility to exchange point for other types of rewards, for example monetary discounts. Furthermore, points also enable users to track their progress and to compare it with friends and colleagues.

To evaluate the effects of different (combinations of) incentives, SUNSET foresees dynamic and controllable incentive management. It allows for generating and placing incentives in real-time during the entire runtime of the system. This means that weak impact or unintended side effects of incentive offers can be detected early and incentive operators, such as city representatives, can alter incentives and the corresponding awards accordingly. For example, city operators can quickly set up incentives to prevent traffic jams after a large concert by motivating visitors to use public transport. In case of temporary overloading, operators can quickly react and issue another incentive to motivate people to stay in the area longer (by offering a free coffee nearby).

C. Social Networking

SUNSET also uses existing social networks, like Facebook, Foursquare, or Twitter, to motivate users to change their travel behavior. Their social sharing infrastructure is ready for users to share and advertise their rewards, achievements, and progress with their friends and other people and get feedback from them. Social networks can also support competition as a gamification feature [37] and create a more playful experience. They can be powerful tools for inducing behavior change as users can compete with each other by sharing and comparing their achievements. Social networks can also trigger conformance to group behavior, especially within a community of people with similar goals and interests.

IV. TRIPZOOM

The tripzoom system is a concrete implementation of the general SUNSET approach and consists of three parts: a mobile application (app) that encourages users to improve their mobility behavior, a Web portal that introduces tripzoom to novel users, and a city dashboard that allows providers to manage tripzoom and its different features.

A. Mobile App

The tripzoom app for iPhones and Android devices is the center of the tripzoom system and makes its main features available to users. To provide these features, the app uses the sensing capabilities of modern mobile devices (e.g., GPS, accelerometer) to detect, measure and track the movements of their users. This raw sensor data is filtered, refined, and finally turned into useful mobility data about places, trips, or transport modalities. This data can later be used to derive the travel behavior of users and give recommendations for how to improve it. The app also visualizes mobility data in different ways and allows users to interact with them. The different features for visualization and interaction are represented by the tabs "Community", "Friends" and "Me" in the user interface of the app (Figs. 1 and 3).

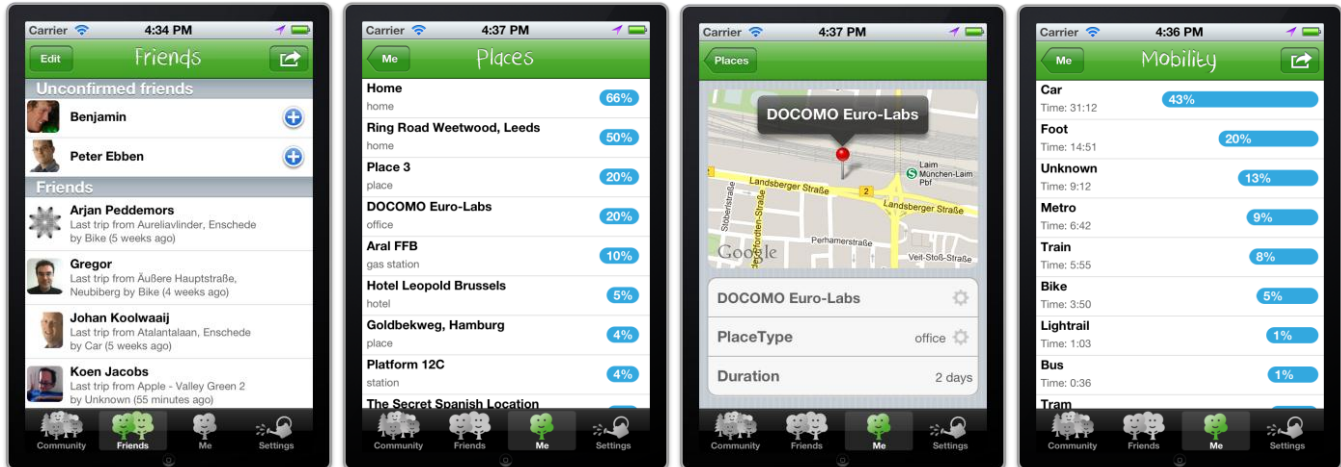


Figure 3. Visualizing mobility data in the tripzoom app

- **Community:** This tab gives an overview of how well the user of the app performs compared to the whole tripzoom community (Fig. 1, right). Four different visualizations illustrate this performance regarding saved money and CO², health and collected points (Fig. 4). If a user performs better than the community average, the respective illustration is more positive, if he performs worse, it is more negative.
- **Friends:** This tab shows the list of friends in the tripzoom community. The list can be managed on both the mobile app and in the Web portal. Every list entry provides additional information about a specific friend, for example about his last trip or trip statistics.
- **Me:** This tab contains all information that is related to the user of the tripzoom app (Fig. 1, left). It provides detailed information about his mobility profile, including visited places, individual and frequent trips (“trails”) or statistics on travel modalities (Fig. 3). It also manages challenges that a user tries to achieve and gives an overview of rewards he has earned.
- **Settings:** This tab contains different options for the management of the tripzoom app, including settings for privacy, profile information, or sharing data.

B. Web Portal

The tripzoom Web portal is the main entry point into the tripzoom experience for new users and consists of two main parts: The landing page advertises tripzoom to interested users, explains its features, provides background information and links to the App Store and Google Play from where users can download the tripzoom app for iPhones and Android devices. The landing page is also a first step into the tripzoom community as it provides links to tripzoom pages on social networks (e.g., Facebook, Twitter, Google+ and Foursquare) and shows updates from Facebook and Twitter feeds. In addition, a community feature provides anonymous and aggregated real-time statistics about the performance of users in the three living lab cities regarding the number of

trips or the amount of CO² that is saved through improved personal mobility.

On the landing page, users can log in to their accounts or create new ones. The portal provides all functionalities to let users maintain their accounts, edit their profiles, or manage settings. As the portal puts a focus on social features, users can create blogs, send messages, invite friends and manage their relationships with them, e.g., by categorizing them as “family members”, “close friends” or “colleagues” (Fig. 5). An activity stream gives a dynamic overview of interesting actions that users carry out in the portal, such as creating new blog posts or accepting friend requests.

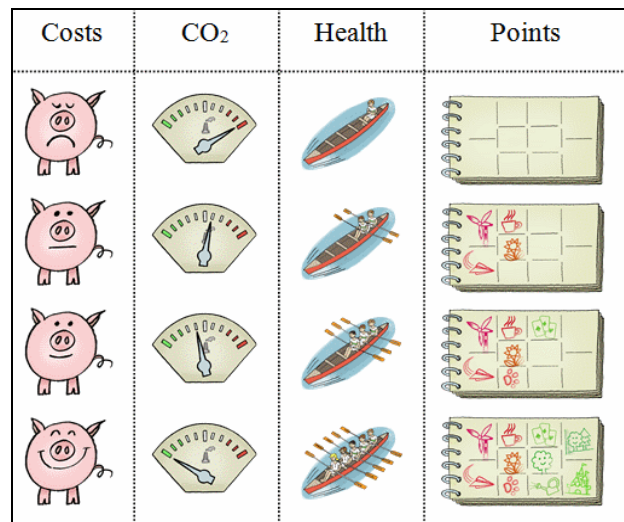


Figure 4. Visualizations of user performance

C. City Dashboard

Next to the Web portal and the mobile app, tripzoom offers a service called city dashboard that allows city authorities to monitor and manage the incentives and reward system. They can add new incentives and specify for which

target group and in which situations these will be triggered. Furthermore, they can get an overview of the current and past mobility situation in the city to design suitable and effective incentives. The city dashboard offers a live view on various aggregated statistics and anonymized data of the users within a city with which operators can check and evaluate the current state and impact of incentive measures. This approach can be used to influence overall mobility behavior (e.g., fewer cars in the city) or to target specific goals, e.g., optimize the use of alternative travel modalities before and after large events.



Figure 5. Friend management in the tripzoom Web portal

V. ARCHITECTURE AND IMPLEMENTATION

tripzoom follows a client-server architecture offering a service infrastructure that provides a set of core mobility and social networking services guarded by a security layer. As described above, users interact with one of the smartphone clients for iPhone or Android or with a Web user interface. City controllers can make use of a city dashboard view, which provides access to city wide mobility information and incentive control. Finally, 3rd party services such as the social networking applications Facebook and Twitter expand the reach of tripzoom information and allow for personalized sharing of mobility information.

In the following, we provide an overview of the general architecture with its main components and some detail about the central functionality, the collection and interpretation of the users' movement data to build mobility profiles. The tripzoom server side consists of a set of core services providers, Web user interfaces, and programming interfaces to 3rd party services, data, and applications (Fig. 6). It delivers core services including incentives, mobility monitoring, and basic social networking services.

- **Personal Mobility Store (PMS):** Collects raw measurements from mobile clients and preprocesses them as input to algorithms for mobile pattern detection.
- **Mobility Pattern Detector (MPD):** Receives data from the PMS and employs sophisticated algorithms to detect

patterns for individuals, groups, places, regions, routes, or vehicles such as bus lines or taxis.

- **Relation, Identity, and Privacy Manager (RIP):** Provides a homebuilt social network implementation and organizes the privacy policies of users based on their social relations or ad-hoc groupings computed by the MPD.
- **Social Network Connector (SNC):** Connects the internal social network (RIP) with existing social networks such as Facebook or Twitter to facilitate user registration, information sharing (e.g., a notification on the successful completion of an incentive), importing contacts, or showing visualizations from the MPD.
- **Incentives Market Place (IMP):** Provides a platform to offer rewards, recognition or real-time feedback as incentives to encourage travelers to improve their travel behavior with respect to the system's and an individual's objectives. The IMP matches available challenges with mobility patterns from the MPD, individual user profiles and preferences from the RIP, general transport information, and can publish performance and events using the SNC.
- **Context Harvester (CH):** Harvests all information required to populate the user's buddy list from all server-side components, such as the RIP for the user profile, the PMS for the last location and trips, the MPD for mobility patterns and the IMP for rewards gained with incentives.

Additionally, the tripzoom server provides a Web portal where mobile users can view their mobility profiles online. 3rd party applications can request access to services provided by the core service provider components after obtaining the user's consent. The distributed system is implemented building on Representational State Transfer (REST) and JavaScript Object Notation (JSON). This supports loose-coupling between components, clear application programming interfaces, and independence of platform and programming language. The security layer uses OAuth, a simple mechanism to publish and interact with data that needs access control. OAuth is a de facto standard used by many systems such as Facebook or Twitter. The tripzoom social network features such as the Social Network Connector build on the open source social networking engine ELGG [38]. Using such a platform has the advantage that users are not required to use a specific network and it simplifies the integration with other functionalities that the portal and the mobile application offer.

The mobile devices of tripzoom users serve as clients to provide mobility data and to present transport information and incentives to guide the mobile user's travel behavior. Correspondingly, the mobile client comprises components for mobile sensing, graphical user interfaces and secure communication with the server (Fig. 6). The sensing component is responsible for gathering mobility sensing data from sensors, to preprocess the data thereby removing redundant and low quality items, and then to upload them to the tripzoom server. Some sensing data elements such as location and battery level can be obtained from onboard

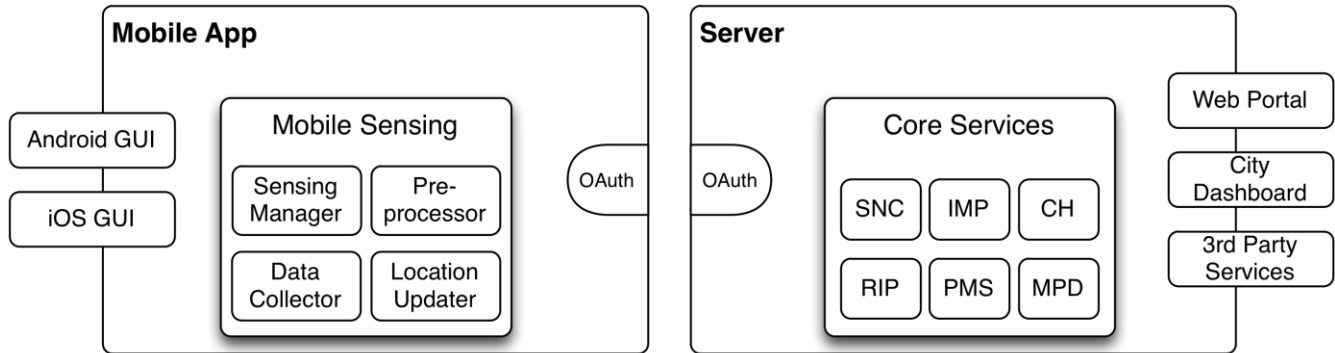


Figure 6. Architecture of the tripzoom system

mobile device sensors. Other data can be incorporated from external sensors, such as step counters or bike sensors. Currently, the tripzoom app supports a range of sensors based on the ANT+ protocol such as the Fitbit Tracker [39] or the Wahoo Cycling Speed/Cadence Sensor [40]. There are four sub-components in the mobile sensing pipeline.

- **Data Collector:** Gathers raw measurements from built-in mobile device sensors as well as externally connected sensors.
- **Sensing Preprocessing:** Applies algorithms to reduce the noise and size of the gathered data, to recognize stationary and travelling situations, and computes initial trip modalities based on the gathered data and the type of the corresponding sensor source.
- **Location Updater:** Decides when to upload the sensing data to tripzoom servers and uploads them when appropriate.
- **Sensing Manager:** Activates, deactivates and adjusts the available sensors and sampling rates to optimize energy consumption as well as data quality.

The social and UI components provide the user interface showing the users' mobility profile (mobility profile visualization), live status of their friends (buddy status and social networking), and receive incentives for a healthier and more cooperative mobility behavior (incentive presenter). A security and communication component is responsible for authenticating mobile users to access their sensitive personal mobility data and to synchronize the mobility, incentive, and social network data between tripzoom mobile clients and the tripzoom server. Upload and download links to push data to and query data from the tripzoom server is implemented by a communication manager module.

Another important component to keep the users up-to-date and to be able to request their feedback on the spot is integrated in the mobile notifications component. This is used to published new incentives, to inform about earned rewards, and to send experience sampling questions. As it is based on the respective mobile operating system's notification mechanism, it can deliver messages even when the phone is in sleep mode.

VI. MOBILITY SENSING AND MINING

tripzoom uses various technologies in mobile phones (e.g., GPS, Wi-Fi, accelerometer) to detect or deduce the 4 Ws of personal mobility: when do people move, where (via which route), with whom, and using which modality (e.g., bike, car). While personal mobility data allows detailed, individual tracking, only a small part of the population can be expected to participate. Still, the goal is to get a comprehensive mobility profile per traveler (Fig. 3) covering a 24/7 period. The use of mobile phone sensors and battery power has to be carefully balanced with the measurement accuracy to be achieved. In the following, we provide more details about how tripzoom senses, gathers, and analyses data from mobile phone sensors keeping the additional energy consumption to a minimum. Fig. 7 gives an overview of the three main processing stages for mobility sensing and mining:

- **Mobile Sensing:** Location data are the key to construct a person's mobility profile. Various data sources from a smartphone's sensors need to be gathered, outliers must be removed, and data transmission optimized.
- **Trip Reconstruction:** This continuous but often noisy location data has to be categorized as a series of static periods and trips with potentially different travel modalities. To get the actual route of the trip, the location trace is mapped onto the road or rail network.
- **Pattern Mining:** Location points and traces are examined to identify frequently visited places and regular trails, such as commuting routes. This information is crucial for isolating trips that will have the largest impact on the user's mobility behavior when changed.

A. Mobile Sensing

Information from mobile device sensors (e.g., GPS, Wi-Fi, and GSM measurements) is combined into one location model that can deal with the varying accuracy of location measurements. These location signals contain a lot of noise and outliers. Especially, the accuracy of GSM data is usually low and the reported locations may be hundreds of meters away from the actual locations of the phone.

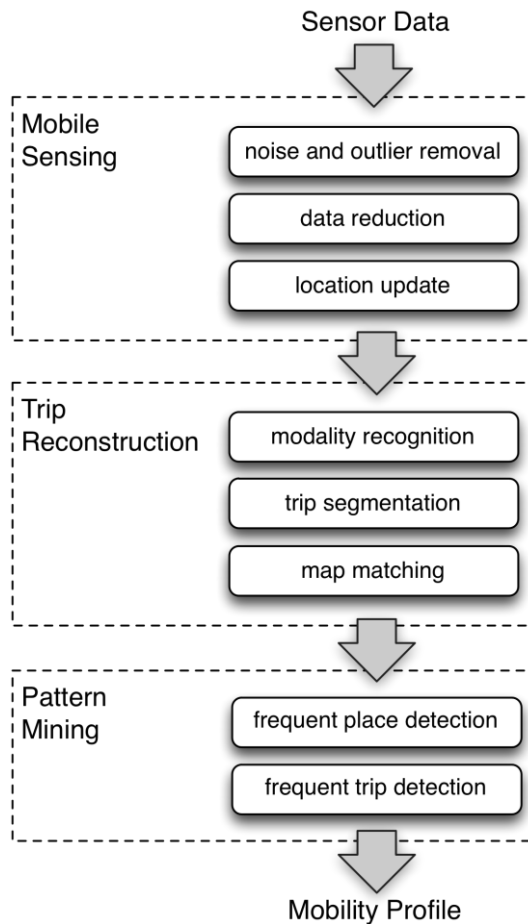


Figure 7. Mobility sensing overview

We designed a location update approach that combines location updates to the tripzoom server with noise removal and data reduction. For a smartphone with GPS, Wi-Fi, and GSM location sensors (in case of Wi-Fi and GSM, locations are computed by a central service provider like Google or Skyhook [41] based on the sensing data provided by the smartphone), tripzoom registers a location change listener to continuously receive location data.

As shown in Fig. 8, our approach considers four scenarios for a location update. If, as shown in Fig. 8a, the new location q is far away from the old location p and the following location r , but the time difference is little (i.e. the calculated speed from p to r through q is high), the update q is considered an outlier. Subject to further empirical studies, we use 50m/s as the threshold of bad data selection. Fig. 8b depicts a common scenario that the new location q 's error range is much worse than that of p . A common example is that p is given by Wi-Fi or GPS, while q is a GSM location. Since the error ranges of p and q overlap, q will be discarded as a low accuracy and unnecessary location update. The missed location will be compensated by the map matching approach detailed in the next section. If the new location q is more accurate (as is depicted in Fig. 8c) or q 's error range does not overlap with the previous location p (as in Fig. 8d),

the new location q is accepted as a good location update and sent to the tripzoom server for further processing.

To keep the amount of data to be processed and transferred small (thus reducing energy consumption, storage space, and transfer times), location updates within a certain threshold distance are also discarded as these add little information for the subsequent route reconstruction.

To implement the trip detection in a battery-efficient way, the tripzoom app listens to 'significant' location changes using Wi-Fi (preferred) or GSM location updates and only enables the battery-hungry GPS if it has reasons to assume that the user has left the (static) location. Attempts to acquire a GPS fix are kept short. If there is no fix within that time, the GPS is turned off and will be re-enabled only after some time. By varying those time intervals, a trade-off is made between consuming battery power and attempting to record the trip as detailed as possible. Our initial tests within a limited user community have shown that battery life can be brought to 20 hours on average, with quite some variations related to differences in coverage (GSM, GPS, etc.) and mobile phone use.

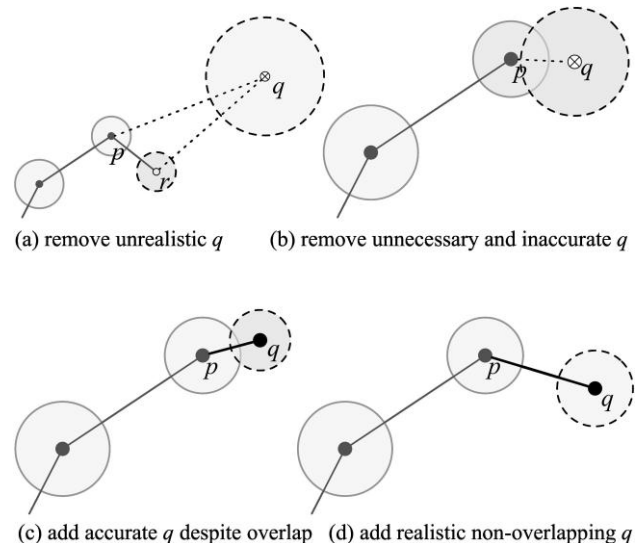


Figure 8. Location update

B. Trip Reconstruction

The task of trip reconstruction is to estimate the route traveled, deduce the places of origin, destination and intermediate stops, as well as to infer the transport modalities used per trip segment, based on the recorded data. Therefore, on the back-end, the goal is to further enhance the data, to apply smoothing and outlier detection to the location data, and to improve trip timings. To gather information on overall modality use and reward calculation, trips need to be stitched and split such that each segment covers a single modality only. To facilitate modality detection, each route segment is mapped onto the underlying infrastructure network. Our algorithms estimate the modalities of each trip based on the location measurements as well as derived parameters such as

speed pattern, infrastructure usage, and origin and destination of the trip. Trip modality recognition applies rules to all gathered information and calculates modality likelihoods. For example, a trip going from one airport to another with an average speed above 150km/h will likely have been made by plane. Users travelling on roads closed for car traffic are likely to walk or cycle depending on their speed pattern, etc. Still, it is important to allow users to manually adapt the recognized modality, in case of any error. The current system has an accuracy of about 70%, which already saves considerable effort compared to manually labeling all trips and is similar to other state-of-the-art approaches [42]. Its algorithm works better on “walking”, “cycling”, “car”, “plane”, and “train” than on other modalities including “bus” and “tram” as these share various properties with similar modalities such as “car” or “train”. An improved approach for recognizing these modalities has been designed, which takes into account bus and tram stops as well as train stations. Trips passing along these places with significant differences between both trip segments, e.g., in speed, will be automatically split at that location, thereby improving the modality detection.

Both trip reconstruction and modality detection strongly rely on map matching. Map matching is the process where the geographic trace in terms of latitude, longitude, and accuracy of the location measurements of a trip is mapped onto the infrastructure network in terms of streets, paths, rails, ferry, and air connections. We have made our own implementation based on existing open-source components [43], and each trip submitted to the PMS is map matched, resulting in a reliable estimate of which infrastructure was actually used to make this trip. This infrastructure usage is then input for the modality detection in the sense that a higher percentage of bus lane usage will favor the “bus” modality, and higher percentage of paths only suited for walking and cycling will decrease the likelihoods for all four-wheeled modalities. Discontinuities in infrastructure usage, like transitions between road and rails, or between rails and air, are proper triggers for the trip splitting algorithm. And the higher the quality of the information on the lowest trip level is, the higher will be the quality of every piece of (pattern, profile or community) information derived from all trips made in SUNSET’s living labs.

C. Pattern mining

To challenge travelers into new – and more optimal – behavior, it is very important for the tripzoom system to know what someone’s current mobility behavior is. Based on this knowledge, tripzoom can notice deviations from the normal routine, which might be the traveler’s response to an attractive incentive. This way, the effectiveness of tripzoom’s incentives can be measured. Personal places, regular trips, called trails in the following, and modality statistics are key components of personal mobility profiles.

Personal places are geographical places that a traveler either visits frequently or for a longer period of time. These personal places will be automatically linked to nearby public places, and the traveler can also adapt naming and typification of these places manually. These places are then

used to assign origin and destination to the personal trips, thereby adding semantics to these trips, as it will not only be classified as a trip from street “A” to street “B”, but as a trip, e.g., from “home” to “work” with the objective to “go to work”, or to a “shopping mall” with the objective to “go shopping”. Personal places are automatically detected by analyzing the static periods of a traveler between two trips. Smart smoothing is applied, and the spikes in the 2D geographical duration-of-stay-histogram are then recognized as personal places in terms of (latitude, longitude, radius). These are used to either update information on the previously detected places, or to add newly detected places. Per place, numerous statistics are computed and persisted, including absolute and relative duration of stay, and their distributions over the hours of the day and the days of the week (Fig. 9).



Figure 9. Personal place statistics

Once tripzoom has knowledge about the personal places of a user, it can also start deducing trails. This is done by clustering all detected trips with the same origin, destination, route, and modality. The clustering is not done on the geographical level, but on the level of Open Street Map [44] infra segments, cancelling out short detours and potentially missing detailed information in the beginning of the trip. All trails with the same origin and destination provide a good overview over all routes and modalities a traveler uses to get from that origin to that destination, and when and how often exactly. Furthermore, all newly detected trips are – if possible – assigned to one of the existing trails consumption if a traveler is on his way to office with a known modality and route for the nth time.

The *personal modality statistics* provide an overview of how much time, distance, costs, and emissions a traveler spends per modality over different periods of time. This is done by analyzing all trips in that period of time and computing the total amounts per modality and other conditions such as whether it is rush hour or not, whether it is raining or not, etc. A perfect capture of a traveler’s normal mobility behavior can be used to add someone to the target group for specific incentives. With the modality statistic at hand, the appropriate triggers can be provided automatically by the tripzoom system.

VII. CONCLUSION AND FUTURE WORK

The tripzoom app supports a personalized mobility monitoring and dynamic incentive system within a social network context. The major contribution of tripzoom lies in the combination of the following aspects:

- tripzoom implements a mobility sensing and profiling service that is accurate and battery friendly. This allows users to monitor their individual mobility behavior 24/7.
- tripzoom supports the operation of innovative incentive programs that will encourage sustainable mobility. The sustainability goals can be achieved through the adaptations in traveller behaviour regarding destination, timing, mode, and route choices.
- tripzoom provides a social networking environment that is attractive to the e-generation. It can be utilized to promote identity recognition and synergy of travellers on sustainable travel behaviour.

The tripzoom system has the potential to meet mobility challenges our society is facing nowadays, with an ever increasing emphasis on efficiency and sustainability. The on-going living lab experiments will not only validate the operational maturity of the app, but also shed light on the impact of tripzoom on the policy goals commonly used in Europe and beyond, such as congestion and emission. The living lab experiments [45] take place in three European cities, where tripzoom is put to the test in the real world: Enschede, the Netherlands; Gothenburg, Sweden; and Leeds, U.K. Participants are recruited from these cities to be active users of tripzoom. Mobility experts at the municipal governments act as living lab coordinators and determine the issuance of incentives among the user groups.

The primary objective of the living labs is to evaluate the effectiveness of tripzoom and its incentive system and how much it can influence the mobility behavior of its users. The evaluation is based on monitoring individual changes by particular population subgroups in particular contexts. The potential impact of these changes at system level can then be estimated. These results will provide valuable input for the improvement of existing incentives and the identification of new ones. Besides the evaluation of incentives, the living labs will provide user feedback of high ecological validity for the operational success of tripzoom and assess the impact of tripzoom on local traffic policies. In the end, the living labs will establish a continuously growing and developing initiative in the cities involved, where a community of citizens, companies and municipalities is formed for realizing their objectives.

Various issues have arisen during the development of tripzoom. On-going research within the SUNSET consortium strives for the further enhancements of the following issues.

- **Robust Mobility Detection vs. Battery Efficiency:** Trip sensing requires the detection of movements and the subsequent matching into mobility patterns. Firstly, the app may fail to detect the mobile phone's movement. Secondly, given that some movements are registered, the app may not fully recognize the trip's origin, destination, timing, and mode, or recognize them in the wrong way. There is a trade-off between detection accuracy and battery consumption. Our research will strive for a highly accurate detection system that consumes as little battery power as possible.
- **Effectiveness of Incentives:** Incentives provide stimuli to individual travelers for changing their behavior. Behavioural adaptation is dependent on the types and operational characteristics of these incentives. This relationship can be used to derive the most effective incentives, which are expected to vary depending on the traffic situation and the group of travellers.
- **User Friendliness:** Usability of an app strongly affects its attractiveness to new users as well as the retention of existing users. A user friendly app needs to be effective, efficient and satisfactory in its specified context of use. For tripzoom, user interface design, user documentation, and error prevention will be further enhanced to improve the user experience.
- **Attractiveness:** Participating in a living lab should be attractive to the average commuter and citizen. It will be interesting to know the share of people who want to contribute to a 24/7 living lab for the common good, especially in comparison to the share that is required to draw valid conclusions on city mobility as a whole.

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