Challenges in Crowdsourcing Real-time Information for Public Transportation

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***Abstract*—Public transportation is a key enabler of mobility in today's urban environment. Transportation service operators are exploring various technologies in order to be able to provide passengers accurate real-time information to plan their journeys. For them, the challenge is often in understanding where, when and how there is a demand. With rapid advancements in mobile technology, crowdsourcing or participatory sensing can be thought of as a medium by which information can be collected, augmented and used for better planning as well as a mode to deliver real-time information to commuters. In this paper, we conduct an extensive review of both literature and applications using mobile crowdsourcing with a focus on the public transportation domain. We identify certain common challenges across various techniques proposed and applied, categorize them and discuss possible future research directions into these areas.**

***Keywords*-Data collection, Mobile crowdsourcing, Participatory sensing, Real-time passenger information systems**

I. Introduction

Cities of today have grown beyond their physical territories. There are a variety of attributes that influence the development and day-to-day operations in a city. Modern cities leverage on the advancements in technology to record factors that influence the dynamics of the city and use it as a means of obtaining feedback to plan better, improve operations, account for resources utilized, etc. Public transportation is one such domain that plays a crucial part in the everyday activities of citizens.

Public transportation operators and service providers define quality of service using various metrics such as travel cost, passengers served, travel time, on-time performance, etc. Beyond these quantitative measures are qualitative measures such as commuter experience [1]. A step towards improving passenger commute experience can be through the provision of real-time transit information systems [2], [3], [4]. Various studies indicate that providing the right information, by itself, is seen to have positive influences on passenger experience. Real-time information can enable the passengers to make informed decisions.

Crowdsourcing can be seen as a new avenue by which real-time information can be collected, augmented and made available for fellow commuters via passenger information systems or mobile applications. Also, crowdsourcing can be used as a mode to verify the accuracy and obtain feedback on the performance of such systems. As smartphones are increasingly being adopted by people, mobile devices can be considered as the primary interface of exchange for crowdsourcing applications. In this paper, we focus on two aspects of using mobile crowdsourcing for real-time public transportation information: 1) to collect transit information about the vehicles and 2) to collect information about the passenger demand.

The paper is structured in the following manner, beginning with the abstract and introduction, followed by the section on how crowdsourcing is defined and some general challenges in this area. This is then followed by a section describing the motivation to use mobile crowdsourcing for public transportation, or real-time passenger information systems in particular. The next section describes various existing literature and applications of crowdsourcing in public transportation. The section following categorizes some of the identified challenges highlighted by various works in the preceding section. We conclude the paper discussing open research areas that need further investigation to effectively use mobile crowdsourcing to develop real-time passenger information systems.

II. Crowdsourcing

Crowdsourcing is defined [5] as a participative online activity where a heterogeneous group of people voluntarily undertake a task of mutual benefit [6]. The modes of participation may differ as identified by [7] either as implicit participation or explicit participation. Crowdsourcing often involves multiple stakeholders: individuals participating in the crowd, the body looking to benefit from or use the crowd input and a platform that enables the participation and collection.

[8] summarize a taxonomy of several crowdsourcing methods based on criteria such as provision of remuneration, how crowd assessment can be used to improve data quality, etc. [9] discuss key challenges in crowdsourcing from the point of view of the participants. For citizens, time is a critical resource. Often they consider participation as a leisure activity. Time dedicated towards participation is time put aside from normal activities such as reading a book, browsing social media, chatting, playing games, etc. Although, studies have shown that there is a boost in participation when participation is via mobile devices

978-1-4799-5705-7/14 $31.00 © 2014 IEEE
DOI 10.1109/MDM.2014.70

[10]. Keeping the participants engaged to contribute is an important area for future research and practice by itself.

[11] and [12] both find that motivation for participation in crowdsourcing as a mix of intrinsic and extrinsic factors. Extrinsic factors include providing compensation and the prospect for public recognition. Intrinsic factors are associated with personal benefits. They both report that compensation is far less a motivation to participate than either the prospect of recognition or immediate benefits. [11] go further and suggest that a good practice is to anticipate the power of public recognition as the major motivator to participation.

People who do not participate are categorized by [13] as those who are *"willing but unable to participate"* and *"able but unwilling to participate"*. The reasons for those who are willing but unable to participate can vary from cultural or language barriers, lack of technical know-how, etc. and for those who are able but unwilling to participate can be due to disinterest, lack of time, no immediate personal gain or relevance, etc.

III. Why Crowdsourcing for Public Transportation?

We define *Supply information* as the information on the public transportation services that are usually related to the transport operators such as vehicle locations, schedule information, arrival times, etc. and *Demand information* as the information about the passengers such as expected load, demography, etc.

A. Where there is no information on the Supply

In most cases, developing cities around the world do not have advanced infrastructure such as fleet tracking systems and sometimes even information considered basic to commuters such as schedule information, bus route maps, route changes, service interruptions, etc. It is seen as an onus on the public transportation operators to provide such information to the public. Collecting information on the real-time positions of buses or route information via crowdsourcing can be seen as a method to implicitly collect supply information.

B. Where there is no information on the Demand

Knowledge of the expected passenger load distribution throughout the day, demographics of the passengers, etc. can be of much help to transportation planners to schedule services accordingly. In most cases, planners use surveys as a method to understand the demand or preferences of commuters. Considering the fact that the demand information does not change drastically in a short period of time as most commuters have regular travel patterns, crowdsourcing applications need to cherry-pick the interesting attributes that are required keeping in mind of the privacy concerns of the users in divulging such information.

IV. Existing Approaches of Crowdsourcing for Public Transportation

NextBus [14] is a bus wayfinding application that overlays bus route and arrival information. A location-based service query submitted to the bus transit server returns information about buses around the user and when they arrive at various stops.

[15] discuss the question of how much historic data can actually be seen useful in predicting current demand. Crowdsourcing applications that generate demand information often collect more information than needed or sometimes miss important attributes that can help in identifying patterns in the demand behavior.

Another technique applied by [16] is called *flocksourcing* or *guided crowdsourcing* where users act like sensors generating data that can be used for improving the public transport services. The comparable difference between crowdsourcing and flocksourcing is that crowdsourcing mostly contain anonymous participants, whereas, flocksourcing is a group of targeted participants. The experiments test and validate three key technical measurements: accuracy of the location sensing, speed of the mobile data network and performance limitations of locally-available hardware. Keeping these in mind, the application design was aimed to minimize costs by leveraging free and open global tools, simplify the user interaction by using icons rather than text, and streamline the number of steps required for a user to start providing data. The results from the experiment were used to build geo-coded bus routes as there were no existing maps for the extensive bus system in the city. Also bus speeds and in turn travel times were measured from the GPS traces. The application included fields to capture demographic attributes such as age group, trip purposes, satisfaction levels, etc. The authors also suggest an alternate method called *fleetsourcing* where the GPS locations reported can be from a device onboard every vehicle rather than citizens having to report such information.

Ubibus is a project that investigates how to integrate private and public vehicles together through collaborative riding [17]. Here collaborative riding is considered as an alternative to public transportation. A *gamification* aspect is brought in to motivate people to participate in such a system as well as to improve adherence to the system usage, thereby also ensuring better data quality. Two surveys were conducted prior to designing the system, an online questionnaire designed for citizens and a field study conducted on two distinct groups of students. The results of the survey were then used as requirements to guide the design of the Ubibus system.

ContriSense:Bus [18] helps commuters plan their bus journey based on information derived from user-contributed data via smartphones. The data contributed by the users are GPS locations with timestamp traces. The derived information from these data points are the segments of travel time between two places. Integrating closed-loop incentive schemes into the system to evaluate supply and demand are proposed future extensions for this system.

[19], [20] present a mobile phone based crowd-participatory sensing system that can predict the arrival time of buses. The challenges that they identify in implementing such participatory systems are *Bus detection*, *Bus classification* and *Information assembling*. Their approach uses mostly automatic methods to detect the mode of transport, checking quality of the data and assembling various samples.

Tiramisu is a co-design project involving transit authorities and commuters. [21] performed workshops and interviews to better understand the interaction between those stakeholders. [22] presents an app, which collects real-time information for predicting arrival times of buses. Moreover, it exchanges information about the load of the bus, including if there is enough space for a wheelchair. In [23] the findings of their field trial are presented.

EasyTracker presented in [24] aims to establish a system, which can work even if there is no available information about bus stop locations and schedules. All information required for providing real-time arrival information is proposed to be collected through fleetsourcing.

The Informed Rural Passenger project [25], [26] is focused on rural areas and intends to support passengers especially during service delays and interruptions. Employing multiple channels such as SMS, email or mobile apps is valuable to riders, as dynamic message boards displaying information about the state of service are barely available in rural areas.

LiveBusTrack [27] is a bus tracking system that employs fleetsourcing, with smartphones, and is designed for covering small scale bus services. It is targeting events, conferences or conventions, which often organize shuttle bus services. Those services usually do not stop at official bus stops and run on properties for which map data might not be publicly available.

V. Identified Challenges

In most cases, we see that there are quite a few technical challenges to enable crowdsourcing for real-time information gathering, especially in countries where the mobile network technology is still in the advancing stages. It is often a challenge to design applications that are resource constrained. Apart from the technical feasibility, there are social or psychological challenges to get people to participate in a crowdsourcing endeavor.

A. Device Hardware

1) Battery Life: Considering that location information is one of the primary inputs for real-time information systems in public transportation, it is challenging to design applications that use GPS being aware of the battery life constraints. In order to tackle this, often applications use lower sampling rates for the collection of locations reports or employ alternate sensors like the accelerometer. Nevertheless, this gives rise to a trade-off with accuracy [16], [19], [23], [28], [27].

2) Computational Power: Although processors used in mobile devices are advancing almost on relatively short cycles, it is unlikely that the majority of the citizens use the latest available smartphones in the market. It is important to decide while designing the application as to whether the device is used as a simple reporting/sensing device or needs to have enough computational power before transmitting the data [16].

B. Network Coverage

Network coverage can be a problem both in large as well as small cities - in large cities due to excessive signal interference and high demand within the same cell, and in smaller cities due to weak signal strength or whitespaces in the network that arises from lesser number of base stations. Since real-time data collection assumes continuous sampling, a network problem could result in lesser samples being transmitted [16], [25].

C. Costs

Mobile crowdsourcing applications are based on smartphones or other devices that require connection to the internet. In some areas, the cost of these devices are high and data packages offered by mobile service providers is expensive. Hence, it is a challenge for applications to reach a critical mass and thus influence the quality of information [29].

D. Data Availability and Quality

1) Route Data Availability: Many implementations assume the availability of fundamental information, such as the geographical locations of bus stops, bus route information or even schedule information. However, in many cities some or all of this information is not available. Map data for roads in rural areas in developing countries or roads on private property, such as exhibition areas, might not be publicly available [27]. The automatic detection of bus stop locations from fleetsourced information is struggling with intersections, traffic signals, hotspots of traffic congestion and stop signs [24]. It may provide candidates for stop locations but still requires manual input. Similarly, the detection of schedules is very difficult due to the increase in variance of arrival times which propagates with each bus stop. [24] report for their experiment a standard deviation, which is ten times higher at the last bus stop compared to the first stop. This problem affects not only the automatic generation of schedules but also the generation of models for arrival time predictions based on historical data. Even in cities in which accurate bus route maps are available, the inaccuracy of location information reported by users' devices might pose a need to complement the route map.

2) Location Accuracy: GPS typically provides an accuracy of up to 10-30 feet, and this accuracy can be improved by using enhancement techniques such as differential GPS [30]. In dense environments, both in terms of population as well as buildings, it is often seen that the GPS systems suffer to a great degree. Tunnels and underground transit is posing additional challenges. Applications that implicitly collect locations from the user's mobile device then need to apply methods to verify the quality of the data, sometimes extrapolate based on the samples available, etc. [28], [19]. If the user location is determined based on the cellular network, additional data needs to be collected about the receiving signal strength of different cell IDs at the bus stops [20].

3) User Generated Information: Commuters expect high quality information that is directly useful for their reference. In some cases, malicious people may report fake information to the system [22], [25]. If there is no comprehensive data validation, wrong information may lead to decreased number of users. In applications where the user is allowed to enter free-text for location descriptions, it is difficult to interpret different representations of the same location by different users [16]. Moreover, information that can improve the coverage may reside as unstructured information in third party services or social networks such as Facebook, Twitter or websites of transit authorities [26], [31]. Improving information quality requires a clear way to integrate, categorize and present the information [29].

4) Real-Time Requirement: The data generated by either the crowd or fleet has a rather short lifespan and is quickly loosing value after its collections [32]. In contrast to crowdsourcing in map creation, it is not sufficient if users collect data without being connected to the internet, uploading it en bloc, employ batch processing and cross-validation by other users. For crowdsourcing real-time transit information, different concepts need to be employed [33]. Especially in the initial phase, it is unlikely that many users are aboard of any given bus so that they can cross-validate the information provided.

5) Dynamic User Base: Although an ideal system should supply reliable arrival information at all time, the group of users contributing information to the system is constantly changing. During certain periods the number of active users might fall under the threshold, which is required for the system to work [33].

E. Trust

1) Privacy Concerns: There is a lot of research towards addressing the problem of maintaining privacy or anonymity, especially in location-based applications. [30] discuss methods on how user anonymity can be preserved especially in location-based applications where the user contributes, either explicitly by sourcing information or implicitly by querying location-based services. It is often the case that there is a trade-off between preserving user anonymity as compared to the comprehensiveness of data being collected [23].

2) Official vs. Unofficial Data: Managers of transit agencies expressed distrust in user generated data. The system should clearly distinguish between official data and data collected by users and make the source apparent to the user of the application [21]. Even fellow commuters do are not confident, if it is not understandable for them how reliable the data is [29], [33]. If no real-time data is available, [23] uses historical data to predict arrival times. The evaluation showed that some users do not trust this data, as they do not know if the system has already collected enough data to produce reliable predictions.

F. Motivation

1) Less Densely Populated Areas: Crowdsourcing applications require a certain critical mass in order to be functional. However, during low demand periods the number of passengers per bus is lower. Thus, the likelihood of having a user on-board of every bus who has installed the app and can record real-time data is lowered as well [33], [26].

2) Non-immediate Benefit: Commuters who actively report issues or share their locations via GPS do not benefit directly from the information they provide [17], [23]. In certain cases, to motivate users to participate, some kind of remuneration is given to participants to contribute information to the system [23]. This extrinsic motivation might harm the long-term participation, if no monetary incentive is given anymore. [34] discuss methods of including features that benefit the user from the location data being collected which not only motivate users to contribute and continue using the app, but also encourage the users to share it with others.

3) Long Term Motivation: [21] find that participants think they would contribute initially, if an active input is required, but would not do so over a long period for every ride. A decrease of sharing was also observed by [23] in their experiments. Moreover, many users tend to be free-riding – they want to benefit from the information of the system, but do not actively contribute. [32] tied to motivate those users to contribute by sending requests asking them to contribute, which had no impact on the number of shared location traces and might have had a negative impact on the user experience. Alternatively, when detected that a user is a free-rider, they blocked access to real-time information until the user contributed. This lead to an increased contribution across the overall user base, however, a higher rate of users abandoned using the app and publicly complained through reviews on the app store.

4) Growth of a critical mass: There is no easy way to calculate the initial critical mass, which is required to make the application work. Even though [28] was able to simulate the level of real-time coverage achieved through a certain level of penetration, it is still hard to foresee how this coverage would affect the perception of usefulness and the growth of the user base. Especially at the beginning, special motivators or fall-back data is required so that the initial lack of coverage does not convert into a lack of value for the user, who then looses interest. Media can also be used as a mode for creating increased awareness which could lead to gaining critical mass [34].

5) Commercial Service vs. Public Good: The results of [21] suggest that users prefer to not take over the same level of responsibility for transit services as compared to driving actions for public parks, which is perceived as public good paid by tax money. Fares paid by riders may frame their view of transit as commercial service and, thus, reduces the intrinsic motivation to contribute for the public good.

G. Usability

1) Manual Input vs. Automatic Detection: If the application used for collecting real-time information requires manual input, such as indication of the bus service number or fullness of the bus, the motivation to use the app frequently is negatively impacted [23]. A system not requiring any manual input would be the best solution. In the past, running background processes in the major mobile operating systems was challenging or impossible. However, this has changed in recent versions. Still, achieving good reliability of automatic detection is still challenging when considering all other constraints, such as GPS accuracy, battery life, computational power etc. Even though vehicle movement can be detected easily, distinguishing non-transit vehicles from transit vehicles during peak hours and differentiating overlapping transit routes requires a certain decision time. During this period a location trace generated by a user does not provide value for the overall system. With their optimal parameters [28] achieved a median decision time of 3 minutes and was able to detect 55% of buses correctly within 5 minutes.

2) Validation of concepts: [23] notes that prototyping systems relying on crowdsourced data is very difficult. Controlled experiments in labs cannot accurately predict whether the system will deliver enough value so that the user is motivated to participate in the long run.

VI. Summary

In this paper, we discuss various methods proposed and applied in real-life scenarios that use mobile crowdsourcing with a focus on real-time passenger information systems for public transportation. We identify various challenges in implementing such systems and categorize them to highlight open areas of research which we would explore further.

Acknowledgment

The authors would like to thank the Economic Development Board and the National Research Foundation of Singapore for partially funding this research.

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