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## **Determination of bus occupancy, routes and stop locations from mobile device reports**

### ABSTRACT

Public transit systems need access to real-time conditions, e.g., occupancy, adherence to schedule, route changes, etc. in order to disseminate accurate and timely information to the public. Bus routes and stops may run into the thousands, and are subject to change. In some locations, bus-stop locations are established by a transit authority, but in an ad-hoc manner based upon local consensus. Up-to-date facts of a bus route, stop location, etc. are determined from reports provided by consumer devices, e.g., smartphones, when users of such devices provide consent to such reports. For accuracy and timeliness, location reports need to be frequent which can drain device batteries. This disclosure provides techniques that enable proximate consumer devices to issue location reports in a collaborative fashion, thereby conserving battery. Further, when permitted by users, entry or exit of commuters is reported to enable determination of bus-stop locations and route alterations.

### KEYWORDS

- Public transit
- Crowdsourcing
- Bus routes
- Location-based services

### BACKGROUND

Real-time information relating to public transit systems, e.g., bus routes, occupancy, bus location, adherence to schedule, locations of popular stops, etc. can be crowdsourced from commuters carrying consumer devices, e.g., smartphones with accelerometers and geo-location

capabilities, from individual commuters that consent to providing such information. To successfully obtain accurate real-time information, certain technical problems need resolution. For example, confirmation that a given user is in fact riding a public transit mode like a bus, and not a taxi or a car, is necessary. Also, a high frequency of geolocation reports, e.g., once a second improves the reliability of crowdsourced information, but can impact available battery on individual devices.

In some locations, bus stops are not always clearly marked along the road or determined by transit authorities. Rather, stops are determined by ad-hoc and popular agreement. Similarly, bus routes themselves are subject to changes depending on traffic, instantaneous popular consensus, etc. Transit information systems need to detect changes to bus stops or route changes in real-time and if accurate, disseminate such information widely. However, currently transit authorities are limited in the ability to detect ad-hoc alterations to stop locations or routes and have no real-time knowledge of such alterations.

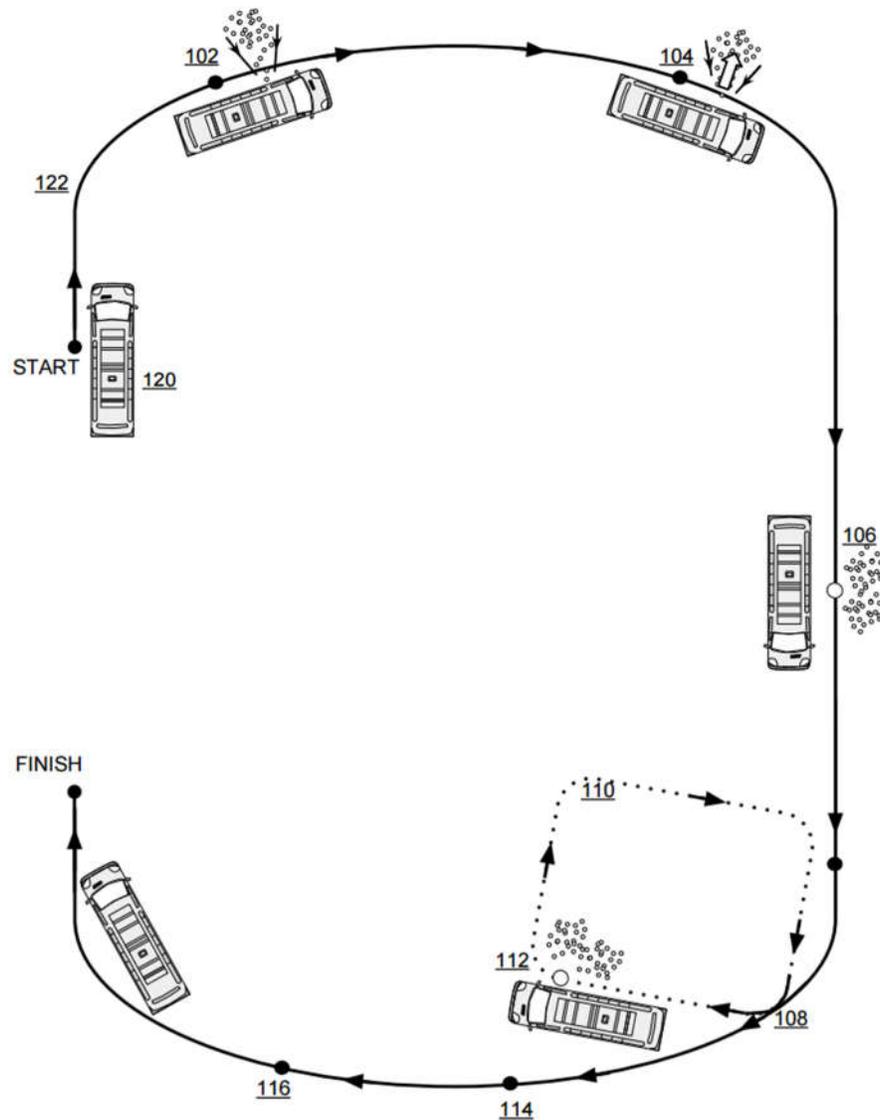
## DESCRIPTION

This disclosure describes techniques that use time-synchronized location reports from a group of smartphones or other consumer devices when users consent to provision of such reports. For example, a group of users is determined as traveling together in public transport based on the location reports. Once identified, individual devices in the group share the burden of reporting location data e.g., GPS readings, accelerometer readings, etc. Such distribution of reporting amongst multiple devices reduces battery usage of each individual device.

Techniques disclosed herein further deduce transit routes based on the location reports, if permitted by each member in the group. Probable locations of ad-hoc stops are deduced by noting locations of events (e.g., GPS location) that are marked by entry and/or exit from the

group. Upon consent by individual users, occupancy data as measured by the size of the group is also obtained, e.g., to determine statistical and/or historical data relating to use of a transit route.

Transmission of location or other sensor data by a user device is controlled by the user and is performed upon the user's specific consent. Personally identifiable information is removed from the data prior to transmission, e.g., by anonymizing or aggregating the data, etc. Further, in providing consent, the user can choose the granularity of data collection, for example, the precision at which location is reported. Still further, the user can specify a frequency at which sensor data is reported, place restrictions on reports from certain locations, limit the total amount of data reported within a given time period, etc. Analysis of sensor data and drawing inferences is performed specifically based on user permission for such analysis. A user can choose the types of inferences that may be drawn from the data, for example a user may permit the detection of the location of a probable bus stop, but disallow use of data that indicates that she boarded or alighted there. Storage and analysis of data is performed in such a manner that no personally identifiable information is collected or used without a user's explicit approval. A user can restrict the use of data or inferences, e.g., make it available only to certain third parties, disallow third party usage, etc. The user can specify the retention time for their data, e.g., do not retain, retain for one hour, retain for one day, retain last  $n$  observations, etc. A user can decline authorization for collection of their data, in which case no data is collected or used. The user can modify their consent and parameters of data collection. The group of commuters from whose devices data is obtained is restricted to those commuters that have consented to collection of such data.



**Fig. 1: Determination of ad-hoc bus stops, route changes, occupancy etc. Solid circles (●) are official bus stops, while empty circles (○) are ad-hoc bus stops. The solid line is the official route, and the dotted line is a change in route.**

Fig. 1 depicts schematically a bus route (122) to illustrate implementation of techniques of this disclosure. As a bus travels the route, users are detected as being co-travelers in a bus, power-efficient location reports obtained from co-travelers that consent to providing such reports, and location reports used to deduce ad-hoc bus stops, route changes, etc. A bus (120) starts its route at the point marked ‘START’ and moves to a first bus stop (102). A bus stop

officially sanctioned by the transit authority is indicated by a solid circle, and the official bus route is the solid line. At the first bus stop, a number of commuters board the bus, which then proceeds to a second bus stop (104). At the second bus stop, some commuters exit, while others enter.

A system that receives locations reports, e.g., from GPS and accelerometers, from devices that belong to commuters that have provided consent, detects that at location 102, a group of users were nearly simultaneously at a relatively confined space. This group is then detected as traveling along the same path, and with essentially the same speeds and accelerations, to location 104. Using analytical techniques such as correlation and filtering, probabilistic reasoning, etc., the system deduces that there is a high likelihood that the group are co-travelers. Further, the system deduces that the group is aboard a bus, that the common path is a bus route, and based on a speed change from pedestrian to vehicular (or vice-versa), identify bus stops. Further, the system determines the size of the group of commuters aboard a bus, as existing members exit and new members enter (based on consent from each existing and new member). Thereby, the system deduces bus occupancy as a function of time and position along bus route. Bus occupancy information is used, for example, to provide a rating such as “crowded” or “quiet” to the vehicle at a later date.

The deductions of bus-routes and stops are also confirmed with increasing certitude, e.g., based on similar observations repeated over successive time periods. The deductions are also compared with known bus-routes and bus stops when such data is available. The deductions can also be confirmed by satellite or street-view images.

Per techniques of this disclosure, membership of the group of co-travelers on the bus is determined as existing members exit and new members enter periodically along the bus route.

Devices of group members take turns in sending location reports. By taking turns in sending reports, the number of reports sent out by any one device is reduced, thereby conserving battery. For example, when there are  $n$  participating devices, each device sends a report every  $n$  minutes. Further, the devices can collaborate, e.g., by locally exchanging information and sending out a consolidated report. Alternatively, such collaboration may be minimal, e.g., on any given turn, a randomly selected device sends out its own report. The diversity of reports submitted by distinct co-located devices increases the accuracy and reliability of reportage.

As the bus travels along the route beyond 104, it encounters a group of people at a next location (106). The bus makes a stop although location 106, which may lack physical signage or structure, is not an official bus stop. The activities of slowing down and stopping of the bus at a point that is not an official bus stop and subsequent entry into the bus of a new group of commuters, is reported back by devices within the bus, by devices just-entered and/or devices just-exited (from devices where the users consent to submit reports). Reports that suggest entry or exit events taking place at a geographical location, e.g., as determined by a machine-learned model for accelerometer data, are combined to deduce that location 106 is an ad-hoc bus stop, indicated in Fig. 1 by an empty circle. Over successive time periods and/or across different bus routes, if the trend of stops and changes in group membership at location 106 are repeatedly observed, then there is increased confidence in the deduction that location 106 is an unofficial bus stop. For locations associated with entry or exit events to qualify as potential bus stop locations, the volume of entry or exit events are normalized, e.g., with reference to local parameters such as population density.

Traveling further down the route, at 108 the bus makes a detour, e.g., due to traffic conditions, road closure, etc. and takes the dotted path (110), a change from the official route.

This change in route is reported by consenting devices. Another group of people notice the altered route and converge upon a point (112) located on the altered route. The bus stops at 112, and the composition of commuters aboard the bus changes after the stop, thus confirming another ad-hoc bus stop. The altered bus route (110) and/or ad-hoc bus stop (112) is inferred with greater certainty, e.g., if such observations are repeated across multiple time periods and/or bus routes.

After exiting the altered bus route, the bus continues its onward journey to the point marked 'FINISH,' stopping along the way, for example, at official bus stops (114, 116), and such activity is determined based on reports from consenting devices.

The described techniques can also be used to detect bus stops that have fallen into disuse, or are no longer in service, e.g., shut down temporarily or permanently. Such bus stops are detected, for example, by the lack of location reports from devices present in or around, by the lack of buses stopping there, and/or by the lack of commuter entry or exit events at known stops along a bus route. In this way, techniques of this disclosure can update a public transit map quickly and automatically, e.g., by adding popular ad-hoc bus stops, removing unused bus stops, correcting the locations of bus stops based on actual usage, etc. While the disclosure refers to bus routes, the techniques may be applied to any type of public transit, e.g., carpools, bus routes, shuttle services, etc.

In situations in which certain implementations discussed herein may collect or use personal information about users (e.g., user data, information about a user's social network, user's location and time at the location, user's biometric information, user's activities and demographic information), users are provided with one or more opportunities to control whether information is collected, whether the personal information is stored, whether the

personal information is used, and how the information is collected about the user, stored and used. That is, the systems and methods discussed herein collect, store and/or use user personal information specifically upon receiving explicit authorization from the relevant users to do so. For example, a user is provided with control over whether programs or features collect user information about that particular user or other users relevant to the program or feature. Each user for which personal information is to be collected is presented with one or more options to allow control over the information collection relevant to that user, to provide permission or authorization as to whether the information is collected and as to which portions of the information are to be collected. For example, users can be provided with one or more such control options over a communication network. In addition, certain data may be treated in one or more ways before it is stored or used so that personally identifiable information is removed. As one example, a user's identity may be treated so that no personally identifiable information can be determined. As another example, a user's geographic location may be generalized to a larger region so that the user's particular location cannot be determined.

## CONCLUSION

Techniques of this disclosure enable crowdsourced discovery of public transit parameters, such as occupancy, route alterations, bus-stop locations, etc. Per techniques of this disclosure, analytical techniques are applied to detect user devices that travel together using a mode of public transport. Device entry or exit events are used to determine additions, removals or other changes to bus stops. Devices on board a bus, with user permission but without active user involvement, collaboratively transmit reports. Such collaboration conserves device battery and provides diversity in reportage. In this manner, changes to public transit are determined

with certainty in a matter of days, using energy-efficient, diverse, and fresh data provided by users, with reduced reliance on the transit authority.