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ROUTEME2: A CLOUD-BASED INFRASTRUCTURE FOR ASSISTED TRANSIT

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ABSTRACT

We introduce RouteMe2, a cloud-based system that was designed to facilitate use of public transit by those who, due to visual or cognitive impairment, or old age, have difficulties traveling independently. RouteMe2 is comprised of a software infrastructure (including a cloud server, a web application, and a mobile application) and a physical infrastructure for fine-grained localization at bus stops or at train platforms. In addition, RouteMe2 uses beacons placed inside bus vehicles and train cars, which allow for identification of an incoming vehicle. Travelers or other authorized individuals (family members, caregivers) can register a trip using the web application. The traveler may receive specific notifications, such as when he or she reaches a desired bus stop or a specific waiting/boarding area within the stop, or when the desired bus vehicle has arrived. Authorized individuals may also track the traveler's trip remotely using the web application, and be notified in case of problems (e.g., if the traveler has taken the wrong bus). A pilot implementation of RouteMe2 was completed at the UC Santa Cruz campus, with a demonstration of the most critical functionalities of the system.

Keywords: Public transit, Accessibility, Localization, Beacons

INTRODUCTION

A large number of people rely on public transportation for their mobility needs, and yet have difficulties using it. Anybody who has taken a bus ride in a city he or she is not familiar with may have experienced the difficulty, uncertainty, and sometimes anxiety associated with determining which bus to take, and at which stop to exit the bus. For someone with poor vision or blindness, taking a bus on an unfamiliar route can become a serious challenge, potentially leading to dangerous situations, such as finding oneself lost in an unknown neighborhood. Likewise, a person with some level of cognitive impairment may become easily confused or feel unsure about which platform he or she should stand on while waiting for a train, or how to negotiate a transfer between a bus and a light rail ride. ADA-mandated acoustic systems that announce the number of an upcoming bus, as well as each stop in a bus or a train, are of great help, but often cannot be heard because of loud background noise, or may be missed if someone was not paying attention. Indeed, some people need to hear the same information multiple times to comprehend it, and hear it again if they become confused.

While some of these people have family members who can drive them to places, this is not a possibility for those who live alone, or when their loved ones are busy with work or school. An alternative is represented by Paratransit, an ADA-mandated service provided by transit agencies that offers individual rides on accessible vehicles. Passengers need to register with the transit agency to reserve a ride the day before the trip, and pay a nominal fee (usually of a few dollars). The cost of a Paratransit ride to the agency is in fact much higher. In rural areas, Paratransit is de facto the only alternative available to its users (1). In urban environments, however, the Paratransit system is widely perceived as economically inefficient with respect to fixed routes (2). Hence, technology that could support safe and comfortable use of public transit by people who would normally rely on Paratransit, would not only increase the independence of these people (who would not need to make advance reservation for a ride), but also increase revenues for the transit agencies.

This paper describes the initial development of RouteMe2, a service testbed comprising three different components: (i) An app running on the passenger's smartphone; (ii) A Bluetooth Low Energy (BLE) beacons infrastructure that enables fine-grained localization and identification of oncoming bus vehicles or trains; (iii) A cloud service that receives data from the user's smartphone, along with static and live feeds from the transit agencies, and produces directions, notifications and warnings that are transmitted to the user's smartphone. RouteMe2 allows a user or an authorized person (family member or caretaker) to register a trip, possibly with multiple legs and using multiple agencies, in a way similar to familiar trip schedulers such as Google Maps. Once the trip is started, users receive continuous, context-aware information, notifications, and warnings, designed to ensure that the trip is executed correctly. Authorized persons can monitor the passenger's progress throughout the route remotely. The system, through a dynamic tracking algorithm that uses all available information, can also detect when an unexpected situation has occurred – if the user entered a wrong bus, for example, or if he or she is waiting for the train on a wrong platform. In this case, RouteMe2 can issue an alert message to the user and to a remote authorized person, who can take the necessary provisions (e.g., re-planning the trip, calling the traveler on the phone).

RouteMe2 is still in its initial development phases, with a pilot deployment completed and demonstrated at the UC Santa Cruz campus. We believe that, once fully developed and widely deployed, the RouteMe2 service could be tremendously helpful for travelers with perceptual or cognitive impairments. It would facilitate independent usage of public transit, enabling safe and comfortable rides. Family members and other individuals concerned with the safety of the travelers would benefit from the ability to remotely monitor the trip, and be alerted when something goes wrong. Ultimately, we believe that RouteMe2 would reduce the need for Paratransit, increase ridership on fixed route transit, and help transit agencies meet their accessibility goals.

PRIOR WORK

Several prior projects have addressed the problem of providing information access to travelers with sensorial or cognitive impairments. For example, the ABLE Transit system (3) was designed to provide location-contingent data (extracted from GTFS feeds) to blind travelers. Azenkot et al. (4) used a Braille display connected to a smartphone to provide access to arrival times (using the OneBusAway system (5)) for blind or deaf-blind travelers. Bluetooth beacons were used in the Accessible Bus System (6) to alert travelers upon arrival of a desired bus. Wi-Fi routers were used in the Public Transit Assistant (PTA) system to support independent travel by blind persons (7)(8). These routers were installed both at bus stops and inside bus vehicles. In-stop routers allowed a user to receive information about the stop location, the bus lines through that stop, and arrival times. In-vehicle routers enabled notification of arrival of a desired vehicle, and, during a bus ride, notification of upcoming stops.

Other projects have addressed the needs of passengers with cognitive impairments (9)(10)(11). For example, the Travel Assistance Device (12) relied on the GPS in the traveler's smartphone while riding a bus to determine the bus location, and to inform the traveler that a desired stop was approaching (a similar system was described in (13)).

The use of BLE beacons for positioning has received increasing interest over the past few years (14)(15). Pilot projects using BLE beacons in transit hubs include installations at selected Massachusetts Bay Transportation Authority (MBTA) rail stations (16), at selected bus stops managed by the Santa Clara Valley Transportation Authority (VTA, 17), and at Gatwick Airport (18). An open standard for digital wayfinding using technologies such as BLE beacons, specifically designed for blind and low-vision traveler, is being developed by Wayfindr.net.

ROUTEME2: GENERAL STRUCTURE AND PILOT DEPLOYMENT

The RouteMe2 system is comprised of a software infrastructure (cloud database, web application, and mobile application) as well as of localization infrastructure (BLE beacons placed at bus stops and train platforms, as well as inside bus vehicles and train cars). In this section, we provide details on both infrastructures, with a focus on the specific pilot implementation that was completed at the UC Santa Cruz campus, demonstrating the main functionalities of the system.

Software Infrastructure

The general software infrastructure of RouteMe2 is shown in Figure 1. Two applications are available for users: a web application, which allows users to register a trip and to monitor the trip's execution, and a mobile application, which runs on the user's smartphone and is used to transmit location information to the cloud server and to receive notifications and directions. Note that the web application can run on the user's smartphone, as well as on any computer or smartphone connected to the internet. This allows authorized individuals to monitor the traveler's trip remotely.

In order to support the desired functionalities of RouteMe2, we defined two different user types: *travelers* and *supervisors*. A supervisor can plan and register a trip for the traveler, and monitor the trip during its execution (and possibly receive alerts in special situations). While a traveler can be his or her own supervisor, the ability to assign a supervisor role to a person other than the traveler could be useful in situations that require special assistance or supervision (e.g., when the traveler is a child, or a person being cared for by a family member or caregiver).

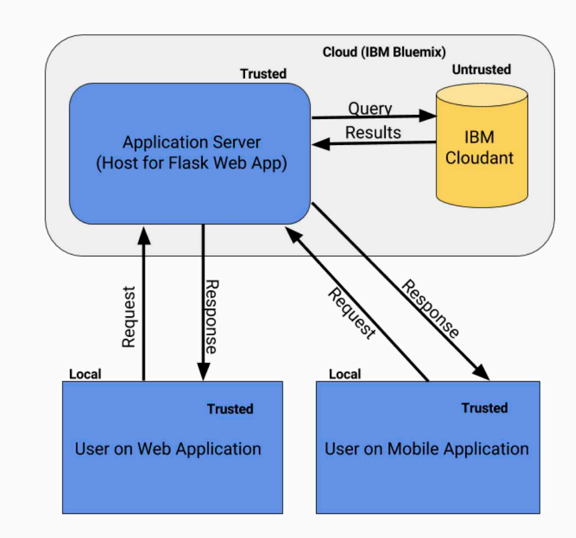


FIGURE 1 RouteMe2 software and cloud services infrastructure.

Database

Our implementation uses an IBM Cloudant NoSQL Document store as a database. The database, which is hosted in the IBM Bluemix cloud server, contains multiple types of documents generated by the application, including user documents (storing personal information), user relation documents (specifying a traveler's supervisor), trip template and trip instance documents (which list information such as start and end points and timing for a trip), and user location documents (which store the current and historical locations for the user, as well as other information such as the means of transportation).

API Design

An API (Application Programming Interface) has been designed to enable creation and management of documents in the cloud server (e.g., updates of the traveler's location). The web app uses the Google Direction API to generate a route for a given trip, including transit and walking legs. A trip-specific *tolerance* value is used to determine when the traveler has strayed too far from the planned route, and needs to be re-routed. The application also estimates the current speed of the traveler while walking, based on the five most recent locations. This is used to estimate whether the traveler will be able to reach the next transit point in time to catch the bus as planned, or if re-routing (or determination of the next bus arrival time) is needed. In addition, the system determines whether the user has arrived and is waiting at a bus stop, on the basis of whether the location sent by the mobile application matches that of the next transit stop in the route. Note that this requires self-localization with higher precision than normally provided by GPS. As discussed in the next section, we use BLE beacons to achieve the desired localization accuracy.

Web Application

The web application, also hosted by the IBM Bluemix cloud server, is written in Flask, a Python-based microframework (19). The front-end development within the web application uses a JavaScript framework known as VueJS (20). The web application allows one to log in, create trip templates, plan and start trips, and view ongoing trips. Google's Direction API provides familiar route visualization embedded within the generated web pages (Figure 2).

FIGURE 2 Sample page created by the RouteMe2 web application displaying a planned trip.

The web application also displays the current user's location, as determined by GPS and/or BLE beacons, along with the uncertainty radius (Figure 5), and information about the user status.

Mobile Application

We developed a simple prototype application, implemented on both iOS and Android platforms, for the purpose of demonstrating the main functionalities of the RouteMe2 system. This application supports transmission of positioning information from GPS and BLE beacons (location updates are sent every 5 seconds), along with other fields such as traveler ID, trip ID, and localization accuracy, among others. In addition, the mobile application is responsible for detecting arrival of a bus as well as permanence of a traveler inside a bus, as determined by connection with the in-vehicle beacon (as explained in the next section).

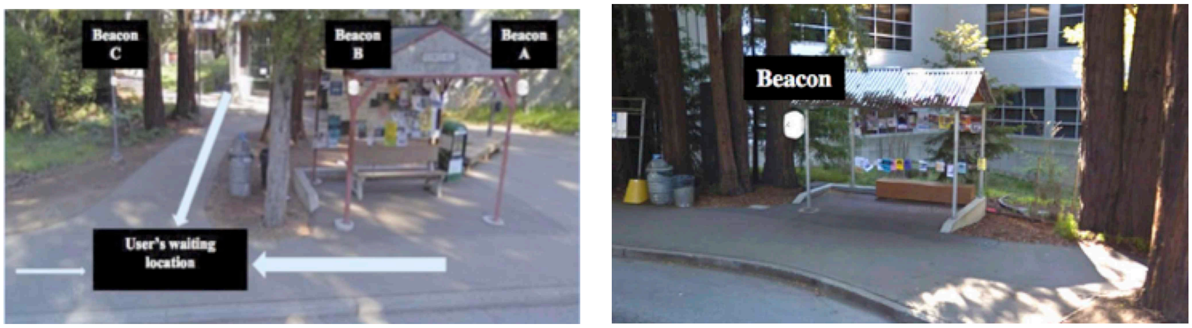
Security

Particular care has been taken to ensure that the information transmitted to the cloud server and stored in the database cannot be accessed by unauthorized individuals. All sensitive user information (including start/end points for a trip, location data, user credentials) is stored encrypted in the database, with access only granted to the user that created the data and to his or her designated supervisor. A lockbox encryption scheme (21,22) was implemented for this purpose. Note that the Cloudant database never stores unencrypted data. Unencrypted data only exists on the Web server, which can be designed to not use permanent storage (RAM-only). This reduces the likelihood of compromise. Another security requirement was to ensure that a user cannot become a supervisor for a traveler without the traveler's permission. This was ensured by verifying (using SHA-256 hashes) that the data in the database documents that contain the relation user–supervisor has not been modified.

Infrastructure for Fine-Grained Localization

Self-localization is critical for correct trip execution. For example, travelers need to know how to reach a bus stop from their location. In addition, we would like to help a traveler identify a specific waiting/boarding area at a bus stop or train platform (see e.g. Figure 3(a)). This would be particularly important for travelers with low vision or blindness, who would otherwise run the risk of standing too far from where the bus pulls over, potentially missing the bus if they cannot reach the vehicle's door quickly enough.

Thanks to its almost universal availability (at least in the outdoors), GPS is the localization system of choice for virtually all existing travel apps. Unfortunately, the accuracy of GPS (which can be as low as tens of meters in urban situations), while adequate for applications such as car navigation systems, is not sufficient for our purposes. For example, GPS typically cannot differentiate between two bus stops across the street from each other, nor can it help one locate the waiting/boarding area. In addition, GPS doesn't work underground (e.g. at a subway station). For these reasons, we rely on an infrastructure of BLE beacons to improve the localization accuracy when necessary.



(a) **(b)**

FIGURE 3 (a) The Science Hill – North bus stop, equipped with three Kontakt.io BLE beacons (shown magnified in the picture). The designated waiting/boarding area is also highlighted. (b) The Science Hill – South bus stop with a single beacon.

BLE Beacons

Over the past few years, Bluetooth Low Energy (BLE) beacons technology has been increasingly deployed for applications such as localization and proximity sensing. BLE beacons are inexpensive and typically run for months or even years on coin-cell batteries. There are two main BLE communication protocols (iBeacons and Eddystone), both supported by iOS and Android smartphones. For this project, we used Kontakt.io Tough Beacons, which, at the default power level, have a nominal range of 20 meters.

In our experiments, we instrumented two bus stops, one with a single BLE beacon, and one with three beacons (see Figure 3). If a single beacon is used, a proximity sensing modality can be enabled by setting a threshold on the received signal strength (RSSI), which is accessible via the Core Location Framework in iOS or the Proximity Beacon API in Android. By placing multiple beacons at different locations (but within transmission range from each other), it is possible to obtain relatively accurate localization from the set of RSSIs (*fingerprint*) from the beacons in range.

While it would be possible in principle to rely on multilateration using standard power decay (path loss) formulas (for the multiple beacons case), a more common practice is to learn the relation between RSSI fingerprints and location through an off-line calibration phase (sometimes called *wardriving*). Calibration requires building a database of RSSI fingerprints from known locations (14)(15). This database can then be queried with a given RSSI fingerprint (as measured by the user's smartphone), to obtain the estimated location of the user. In our experiments, we used the inverse mapping technique proposed in (23), and summarized as follows. Given a RSSI fingerprint, we find the k closest (under Euclidean metric) fingerprints in the database. The estimated location is then set to be the weighted average of the locations associated to these k signatures, where the weights are proportional to the sum of the RSSI of each signature (the weights sum up to 1). In our experiments, we used $k = 4$.

Calibration Calibration of the 3-beacon system was achieved using a simple and effective procedure. We created a polar grid centered around a specific location within the waiting/boarding area, with angular separation of 30 degrees, and radial separation of 0.5 meters (see Figure 4). Ten RSSI fingerprint measurements were taken at each location on the polar grid, with half of these measurement taken with the user holding the smartphone facing the center of the grid, and half while facing the opposite direction. The polar coordinates of each measurement point were then converted to Euclidean coordinates defined on a local reference system, and finally to lat/long coordinates based on the known location of a nearby landmark, and the known orientation of a nearby street, used as reference.

For the bus stop equipped with a single beacon, we simply determined an RSSI threshold corresponding to a distance of approximately 5 meters from the beacon. Note that in this case, there is no need for accurate localization during the calibration phase; only the distance to the beacon (e.g. measured with a measuring tape) needs to be computed.

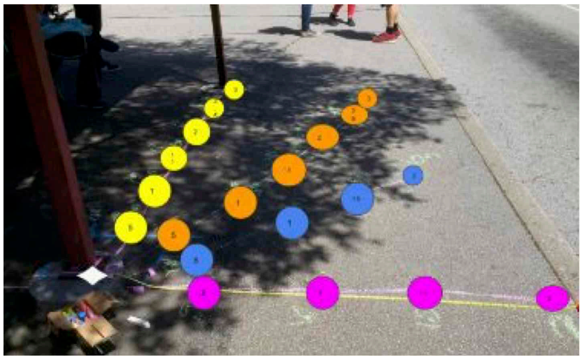
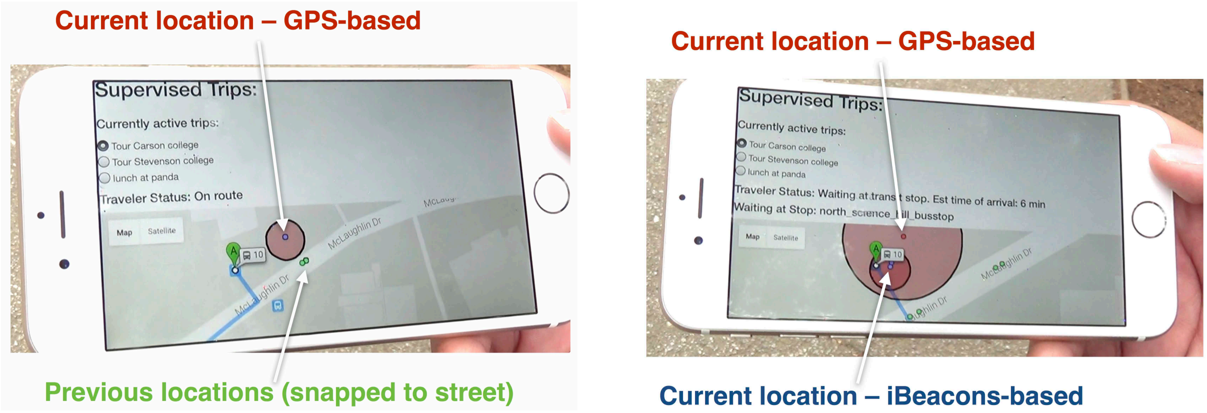


FIGURE 4 An illustration of the polar grid of locations used to calibrate the beacon system.

Accuracy Assessment The localization accuracy of the 3-beacon system was measured by walking with constant speed along a straight segment with known endpoints, and by recording start and stop time (which allows for accurate estimation of the user's location at any time during the walk). RSSI fingerprints were collected at a rate of one measurement per second, and location was estimated using the algorithm described above. Averaged over five data sets thus collected, we found a mean localization error of 3.4 meters. For comparison, the mean localization error of GPS (as measured in the same trials) was of 6.3 meters. It should be noted that while the localization accuracy from beacon RSSI fingerprint was consistent across trials, GPS resulted in errors varying from 3.2 meters to 13.3 meters (over different trials). We noted in our experiments that the localization accuracy provided by the beacon system is highly dependent on the user's orientation; this is likely due to the fact that if the user's body occludes view of the beacons, the measured RSSI drops, resulting in high error variance. It is also important to note that the accuracy of both GPS and beacons system depends on various conditions, such as the presence of nearby tall structures that can occlude view of the GPS satellites, or the presence of people or other occluders that can attenuate the radio signal from the beacons. For the case of the bus stop considered in this experiment, a canopy of redwood trees likely contributed to attenuation of GPS signal, while the presence of a large tree was responsible for attenuation of the signal in some spots within the bus stop area from the beacon marked as 'C' as shown in Figure 3.

GPS vs. Beacon-Based Localization

As discussed above, while universally available (in the outdoors), GPS provides, in general, a much lower localization accuracy than the BLE beacon system. For example, Figure 5 (a) shows a situation in which the user, while walking towards a bus stop (marked as 'A'), was out of range of the beacons in the bus stop, and thus could only rely on GPS. In Figure 5 (b), two localization estimates are shown, one from GPS and one from the beacons (the latter with a much smaller confidence radius). The GPS confidence radius was accessed via the Android Location class; it represents the radius of the smallest circle centered at the estimated location that is assumed to contain the true location with probability of 0.68. In order to obtain a similar measure of uncertainty for beacon-based localization, we regressed the variance of measured localization error on the sum of RSSI values in the fingerprint.



(a) (b)

FIGURE 5 Views generated by the web application in two different moments while the traveler was approaching the bus stop marked as 'A' in the map. The circles represent the confidence radius for localization provided by GPS or beacons.

The difference between the two systems' accuracy is also clearly visible in Figure 6, showing a sequence of locations estimates for a user walking along the straight path depicted by a yellow segment. This figure shows by means of red dots the user's location as measured by GPS, with associated circles of confidence. Blue dots represent location estimates (and associated confidence circles) based on the measured RSSI fingerprints. Note how these estimates better represent the actual path walked by the user (even though relatively large errors are occasionally observed).

The white dots in the figure represent location estimates obtained by statistical fusion of the two types of measurements. Specifically, these values are computed as the weighted average of GPS and beacon-based measurements, with weights inversely proportional to the variance of estimation. Fusion of GPS and beacon-based localization could be particularly useful in situations with low density of beacons (and thus poor associated accuracy). For example, in the case of a single beacon placed at a bus stop (which, as mentioned earlier, can be used only for proximity sensing), fusing information with GPS could allow users to estimate on which side of the beacon they find themselves on the sidewalk. This could be useful for a person (e.g. a blind traveler) to understand where to move in order to get closer to the beacon.

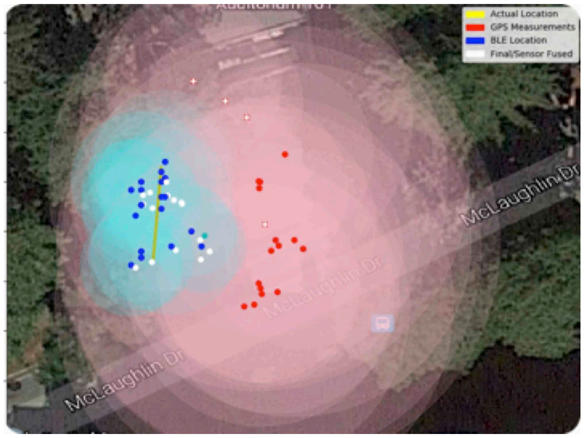


FIGURE 6 Location estimates and confidence circles computed at different times while the traveler was walking along the straight path represented by the yellow segment. Blue: beacons; red: GPS; white: statistical fusion of localization from beacons and GPS.

Vehicle Arrival Notification

Besides aiding in self-localization, BLE beacons can be placed inside a bus vehicle or train car, allowing passengers waiting at a bus stop or platform to be notified upon arrival of a specific vehicle. Thanks to the short discovery time (on the order of one second), notifications can be produced while the vehicle is still approaching the stop, or as soon as it pulls over. Receiving reliable information from the system that the vehicle that has just arrived is the correct one may be very important for travelers with low or no vision, as well as for travelers who are uncertain about the bus or train line to take. Another advantage of in-vehicle beacon placement is that the user's app can sense the beacon throughout the ride, enabling the cloud system to ascertain that he or she is riding the correct bus, and produce contextual information (e.g., notifications about the upcoming destination stop). Note that, while it is possible in principle to identify if a traveler is riding a certain bus line based on the GPS trace of his or her smartphone (24), this can be difficult in the case of different lines sharing a common portion of the route. In contrast, detection of a in-vehicle beacon over an extended period of time provides positive confirmation that the user is riding that particular bus or train.

Two problems need to be addressed for successful vehicle arrival notification. The first problem is disambiguation of situations when two (or possibly more) bus vehicles arrive at the same time, with the user's smartphone in the transmission range of the beacons from both vehicles. It is conceivable that the ID of the closest beacon could be determined on the basis of the received RSSI; we plan to conduct future studies to confirm this hypothesis. The second problem is the association between a beacon ID and a specific bus line. Beacons identify bus vehicles; however, the same vehicle could be (and typically is) used for different lines in different days. This calls for a mechanism to expose the vehicle's identity. For example, if the transit agency provides a GTFS Real Time feed, this information could be embedded in the trip's optional *VehicleDescriptor* field.

FIGURE 7 A UC Santa Cruz campus bus vehicle that was equipped with a Kontakt.io BLE beacon.

CONCLUSIONS

We introduced RouteMe2, a cloud-integrated service designed to facilitate use of public transit by those who may have difficulties with tasks such as identifying a bus stop or train platform, finding the waiting/boarding area in the transit stop, ascertaining whether an incoming bus or train is the desired one, and determining when to exit from the bus or train. Rather than addressing each of these functionalities independently, RouteMe2 takes a global approach, effectively operating as an end-to-end travel assistant. Importantly, it allows authorized individuals (family members, caregivers) to monitor the traveler's progress in a registered trip. RouteMe2 is supported by an infrastructure of inexpensive BLE beacons, placed at bus stops/train platforms and inside bus vehicles and train cars.

A pilot implementation of the RouteMe2 system was deployed on the UC Santa Cruz campus, demonstrating some of its most critical functionalities. Future work will include adding access to available GTFS Real Time feeds for just-in-time re-routing (e.g., if a bus line is delayed), improved accessibility of the mobile application (e.g., using VoiceOver for blind traveler), and tests with a larger-scale deployment with partnering transit agencies.

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