Integration of GPS-enabled Mobile Phones and AVL – Personalized Real-time Transit Navigation Information on Your Phone

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This paper is a condensed version of the final report for the Transportation Research Board's Transit Innovations Deserving Exploratory Analysis (IDEA) program Project 52 - "Transit Assistant Device (TAD) to Help Transit Riders"

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ABSTRACT

Navigating the transit system can be a major obstacle for attracting new riders, especially for special needs populations and tourists. For those with cognitive disabilities (approximately 14.3 million Americans, or 6% of the population), it is especially daunting to plan and execute a trip without receiving personal assistance from travel trainers provided by the transit agency or other group, especially on their first few trips. A Travel Assistance Device (TAD) software prototype for GPS-enabled mobile phones was developed to aid new transit riders, especially those who are cognitively disabled. Informational prompts are delivered to the rider in a "just-in-time" method that triggers the phone to vibrate and deliver audio and visual messages when the rider should signal the driver he or she is approaching his or her stop and exit the vehicle. This paper reports the results of a study sponsored by Transportation Research Board Transit IDEA project which integrated communication with an Automatic Vehicle Location (AVL) system for transit vehicles into the TAD system. Utilizing AVL information allows new features to be provided to transit riders via their cell phone such including personalized notices of the estimated vehicle arrival time while they are waiting for the bus, notifying riders when their specific bus arrives, and providing the rider with identifying information so that they board the correct bus if multiple buses are present. Implementation considerations including the limitations of accessing AVL data for real-time consumer use, data integration between different transit agency data sources, and software application overhead considerations (e.g. wireless data communication) on mobile phone functionality (e.g. battery life) are addressed.

1 INTRODUCTION

Navigating the transit system can be a major obstacle for attracting new riders, especially for special needs populations and tourists. Approximately half of the general population surveyed in a 2008 study by the National Center for Transit Research (NCTR) cannot successfully plan an entire trip on a fixed-route transit system using printed information materials *(Cain, 2004).* For those with cognitive disabilities (approximately 14.3 million Americans, or 6% of the population), it is especially daunting to plan and execute a trip without any personal assistance from travel trainers provided by the transit agency or other group, especially on their first few trips, *(U.S. Census Bureau, 2006).*

The Center for Urban Transportation Research (CUTR) and the Department of Computer Science and Engineering (CSE) at the University of South Florida (USF) have established an ongoing partnership over the past several years that focuses on the research and development of cutting-edge mobile technology for transportation applications. Previous applications were developed with funding from the Florida Department of Transportation (FDOT) through the NCTR and have focused on the use of Global Positioning System (GPS)-enabled personal mobile phones and the development of location-aware artificial intelligence software systems. The knowledge gathered from these projects, along with recent advances in the last several years in mobile communications technology, led the research team to conclude that GPS-enabled mobile phones could now serve as a personalized Travel Assistant Device (TAD) for public transportation. These off-the-shelf mobile phones are a fraction of the cost and physical size of previous portable technology systems, therefore more affordably available to the public. For example, the phones used by the research team to test the TAD system in 2009 can be purchased with a cost to the end user of approximately $40 and have the form factor of a typical consumer-grade “flip-phone.”

Funding from NCTR and FDOT supported the initial development of the TAD software prototype, which used commercially-available multimedia cellular phones with built-in GPS to aid new transit riders, especially those who are cognitively disabled, *(Barbeau et al, 2009) (Barbeau et al, 2008).* Informational prompts are delivered to the rider in a “just-in-time” method that triggers the phone to vibrate and deliver audio and visual messages when the rider should pull the stop cord and exit the bus. Automated alarms can be triggered and the travel trainer and/or parent/guardian remotely alerted if a rider deviates from their pre-determined path.

Initial development and testing of the TAD prototype took place in 2008 with the assistance of Hillsborough Area Regional Transit (HART) in Tampa, Fl. The HART system serves Hillsborough County, Florida, including the City of Tampa with a service area population of over 578,000 in 2007 covering over 254 square miles. HART operates approximately 30 directly operated paratransit vehicles, over 160 motorbus vehicles, 34 vanpools, and a trolley system. The HART system carried over 82,000 unlinked passenger trips on paratransit and over 12,000,000 unlinked passenger trips in 2007. The paratransit system operating expense per passenger trip is $31.45 while the operating expense per passenger trip for motorbus service is $4.09, *(Florida Transit Information System, 2009.)*

Potential benefits of the TAD include increased transit ridership, decreased costs to the transit agency by enabling riders to use fixed-route transit that would have otherwise used paratransit, increased independence and improved quality of life for transit riders, and increased productivity of transit agencies’ travel trainers whose job is to provide one-on-one instruction for new riders or existing paratransit riders on how to use fixed-route transit. TAD will not replace travel instruction, but rather be a valuable tool, for both travel trainers and trainees, to expedite the learning process of using public transportation and reduce the learning curve for all transit riders. While TAD was originally created to help riders with cognitive disabilities, TAD could easily be used by any traveler.

The initial TAD prototype triggers the phone to vibrate and deliver audio and visual messages when the rider should pull the stop cord and exit the bus. The Transit IDEA project discussed in this paper further developed TAD, a GPS-enabled mobile phone application, by integrating communication with an Automatic Vehicle Location (AVL) system for transit vehicles into the TAD system. This communication supports advanced TAD features, based on the real-time location of the transit vehicle in relationship to each rider’s real-time location, including providing personalized notices estimating when the bus will reach their current position via the rider’s mobile phone, notifying riders when their specific bus arrives, and providing the rider with identifying information so that they board the correct bus if multiple buses are present. Real-time bus locations are also shown on the TAD website map.

TAD consists of several components with this project adding new modules that interact with the Hillsborough Area Regional Transit (HART) system to provide real-time vehicle location and estimated time of arrival information as shown in Figure 1.

TAD is a software system compromised of four individual software components:

- TAD mobile phone software, which provides real-time alerts to the user
- TAD web application that interacts with the mobile phone software
- TAD Web Page, where users plan new trips
- TAD Toolkit application that handles the import, export, and processing of transit data

The TAD system interacts with two HART components: the database server containing HART AVL data and a HART web service that provides estimated time of arrival (ETA) information for a particular bus, stop, and route.

Using the additional HART systems, new features in the TAD application become possible. TAD mobile phone application can display real-time ETA information to the user waiting for their bus at the bus stop. Additionally, the TAD web page can show the real-time bus locations for all buses relative to the active user. Using the ETA, TAD alerts the user when a set number of minutes remain before the bus is to arrive, and then notifies the user as the bus is actually arriving at the stop.

2 RESEARCH METHODOLOGY

While the following section describes development tasks to integrate TAD and HART's AVL system, subsequent sections of this paper will highlight interesting or unexpected results that significantly affected the investigation, either positively or negatively.

1. Define the functional requirements for integrating transit AVL data into the TAD system to support new features (e.g. provide user with an estimated arrival time of a bus while they are waiting at their bus stop, providing information about real-time vehicle position via the TAD website).

2. Review existing literature: current standards as they relate to TAD-AVL system integration (e.g., Transit Communications Interface Profiles, Google Transit Feed Specification), and research related to the experience of individuals with cognitive disabilities using public transportation *(Barbeau et al. 2009).*

3. Develop and assign tasks to meet those functional requirements, based on the outcome of steps 1 and 2.

4. Hire and train computer science and engineering graduate and undergraduate students to carry out supporting tasks in parallel.

5. Obtain real-time remote access to HART's AVL system that was being installed during the course of this project

6. Review/modify functional requirements based on HART AVL system functionality

7. Finalize system design and architecture based on functional requirements and HART AVL system functionality

8. Develop new features for TAD to include

    a. Displaying the remaining wait time for the transit rider while waiting for required bus to arrive at the stop
    b. Alerting the transit rider when the correct bus is approaching the bus stop location
    c. Showing the bus locations in real-time on a publicly accessible webpage.
    d. Refining the notification algorithm for TAD mobile application by overcoming the limitation of the previous one that gave alerts either sooner or later that when bus stops are close together
    e. Exporting cell phone GPS trip data in a format that can be re-played through a phone emulator to simulate TAD trips, allowing preliminary mobile phone software testing without actually boarding the transit vehicle

9. Test the prototype with representative end-users of the product and refine

3.1 Identifying and Meeting the Functional Requirements

Table 1 summarizes the functional requirements and how the new TAD system architecture fulfills those requirements.

The following system components are used within the TAD architecture to provide services to the TAD end-user based on AVL data, (Figure 2).

1. TAD Mobile Phone Application
2. TAD Web Server Application
3. TAD Web Page
4. HART Web Service to provide vehicle estimated time of arrival information
5. HART database containing vehicle location

Components 4 and 5 are new to the architecture and provide AVL-based information to the TAD system.

3.2 Reviewing Relationships to Existing Standards

As part of the design and implementation process, the research team examined the American Public Transit Association (APTA) standards on Transit Communications Interface Profiles (TCIP) to determine applicability to this particular software implementation. Since this project made use of existing data sources that do not implement the TCIP standard as part of this system prototype (e.g. AVL web service and database, Google Transit Feed Specification (GTFS) *(Google, Inc. 2009)*), making TAD TCIP-compliant would not result in a working prototype. However, it is planned that, in future TAD software implementations that will interface with TCIP-compliant systems (e.g. different AVL systems), a TCIP-interpreter will need to be developed that will allow fluid interaction of the TAD system with TCIP-compliant systems.

3.3 Providing Transit Rider with Vehicle Estimated Time of Arrival Information

TAD utilizes an existing web service hosted on HART's server to retrieve an estimate of bus time arrival based on HART's real-time AVL system. TAD cell phone application prompts the user to select a trip to travel when started. Trips are previously planned on the TAD website by the travel trainer, parent/guardian, or if capable, the transit rider.

Using the existing knowledge of the user's planned route (including both bus stop IDs and route IDs), once a trip is selected, the TAD mobile application communicates with HART's web service and displays the estimated arrival time (ETA) to the user (Figure 3). The user does not input any other data about their bus stop or route to see this information. To make this display easy to read, the number shown counts down in real-time second-by-second to illustrate the constant change in remaining time until the vehicle arrives. This display differs from other formats that display the ETA as a clock would and the rider subtracts that from the current time to determine the actual period they will wait until the vehicle arrives at the stop. If there is a change in the actual arrival time based on unscheduled delays, the TAD phone application retrieves this information from HART's web service and updates the display to the transit rider. The phone will vibrate to remind the user when five minutes remain until the bus is estimated to arrive. Once the vehicle is within two minutes of arrival, the phone will display a "Now Arriving . . ." message to the user to indicate that they should be ready to board the bus.

The main screen also includes information regarding the user's selected trip and route. In the top title bar, the trip name is shown, e.g. "Home to Work." Immediately below, the route information appears, making the transit rider aware of which bus he or she should board (e.g. "5 DOWNTOWN" in the case of Figure 3). Finally, at the bottom of the screen, the distance to the destination stop provides the user with the remaining distance to their destination while they are traveling on the bus. The user will receive the "Get Ready…" audible notification with vibration when they are a few bus stops away from their destination. The rider will receive an audible notification when it is time to request a stop so he or she can signal the driver that he or she wishes to disembark the transit vehicle. The phone also will vibrate and display a text printout of the "Get Ready" message on the screen. The design of the main TAD cell phone interface (i.e., the portions not related to AVL information) was based on literature reviewed under the first phase of the TAD project which identifies audio prompts as the most effective and preferred type of prompts for real-time navigation which interferes least with the cognitive process of navigation *(Sohlberg et al.*

2007, Lee et al. 2001, McCallum et al. 2004, and Parush et al. 2005). For more information on this topic, the reader is directed to the TAD Phase 1 Final Report *(Barbeau et al 2008)*.

3.4 Web Page Showing Real-Time Buses Location

One of the challenges uncovered during this project was the actual delay between the location of the bus and the transmittal of that location. The near real-time locations of buses are retrieved from a SQL Server database maintained at HART. There is an estimated delay of approximately 90 seconds between when a vehicle position is calculated on-board using GPS to when the information is made available to the TAD system through HART's database. HART vehicles are scheduled to report location to the AVL system at a minimum of once per minute and propagation delays account for the additional time before the new information is visible to the TAD system. The Graphic User Interface (GUI) of the TAD web page features new icons to better differentiate markers indicating the position of TAD mobile users and the real-time location of buses. Figure 4 is a screenshot of the new tracking map on the TAD web page. Now, the bus icon represents the location of buses in the map. The person icon refers to the location of transit riders currently using TAD. By clicking on a transit rider icon, the corresponding information (name and phone number) is displayed. In addition, the web page allows making a call (by means of Skype™ Voice-Over-IP software) or sending a SMS text message to the transit rider.

3.5 Updated Transit Rider Notification Trigger Algorithm

While field-testing the first phase of TAD, several limitations were identified in the rider notification algorithm that prompts the user to request a stop when bus stops are close together, *(Barbeau et al. 2008)*. In an attempt to improve this initial algorithm, the research team developed a new rider notification algorithm. This new notification algorithm detects the departure from the second-to-last bus stop instead of a simple radius surrounding the destination stop. It also uses the speed of the bus to determine when to ring the alerts. This combination of features provides a near optimal notification mechanism that alerts the user at the earliest possible time, immediately after passing the rider's second-to-last bus stop.

This rider alert algorithm has been tested on more than two dozen car trips and actual bus rides and has given the proper alerts. The alerts were given in two places, either right as the bus was passing the second-to-last bus stop at high speed or as the bus left second-to-last bus stop after making a requested stop. This alert system, compared to previous algorithm that used a single radius surrounding the destination stop, provided more alert-time to users in most circumstances. More alert time increased the chances of the user pulling the cord at the appropriate location.

3.6 Trip Export in Phone Emulator Format

In refining the TAD mobile phone software and making sure it is error free, it became evident the research team needed a tool to complete rapid tests without having to board a transit vehicle. To facilitate testing, the TAD Toolkit software was modified under this project to allow exporting previously recorded bus trips into a format that a phone software emulator for a desktop computer can understand. The trip information from the database is exported in the following format:

```
<waypoints>
<waypoint time="1000"
latitude="28.054105752" longitude="-82.413940429" altitude="310" />
<waypoint time="1000"
latitude="28.054711717" longitude="-82.415142059" altitude="215" />
</waypoints>
```

In this XML code, time is measured in milliseconds, which means that script spends 1 second moving from the current waypoint to the next. Intermediate positions are automatically interpolated by the phone software emulator based on the amount of time spent moving between the two sets of coordinates, the distance between the two coordinates, and the GPS update frequency used in the emulator. Using this data, a GPS production rate of one fix per second can be simulated. The created XML file is then loaded into Wireless Toolkit phone emulator software and replayed to simulate a bus trip when the emulator is executing the TAD mobile phone application. While there is no substitute for testing new TAD features in the real world due to the uncertainty of GPS, re-using recorded trips allowed researchers to identify potential errors in the TAD software before field-testing TAD on-board a bus. This tool will prove useful in testing future transportation-related mobile phone applications relying on real-time data.

3.7 Additional Features Investigated

The initial concept of utilizing AVL data in the TAD system included other features such as using the bus AVL data for a backup to alert the transit rider if the phone GPS fails while on-board or providing an alert if the rider boards an incorrect bus or exits at the incorrect stop (e.g. is separated from the bus earlier than expected).

After gaining access to the HART AVL system, the research team discovered that the typical amount of time between when the AVL system calculates the on-board GPS bus location and when the TAD system would receive that location from HART's system exceeded sixty seconds. Additionally, a position is typically reported from each bus only once per minute. Due to the uncertainty of GPS (from both vehicle and phone) and lack of high frequency and timely vehicle location updates, it was determined that the tested AVL system could not be used to provide a reliable, adequate backup alert for the rider. It is difficult to build a high degree of confidence in the association between the rider's position and vehicle position under these circumstances and therefore any service based on this information will likely yield an unacceptably high number of false-positives or false-negatives. From conversations with HART, the limited frequency in vehicle location updates is primarily a result of HART's AVL radio system capacity for their particular AVL solution. If other AVL solutions allow a more frequent and timely update rate, an AVL-based backup for rider notification may be feasible on other AVL systems.

4 FIELD TESTING PROTOTYPE

In partnership with HART, twelve families with special needs individuals were solicited to participate in pilot testing of TAD with AVL integration under the TRB IDEA project. In accordance with USF's Institutional Review Board's approved procedures, the pilot test was conducted with three special needs individuals and observers. Other final field tests were conducted by the research team, to evaluate AVL integration system performance and troubleshooting problems as necessary.

For AVL system integration evaluation, the observers noted the following details for each trip and made relevant comments:

- Did the participant have problems finding the bus stop?
- Did the observer help the participant cross the street?
- HART Route # and trip start time
- Starting and ending bus stop IDs and locations
- Were the Participant's and Observer's cell phones showing the same ETA time?
- Did the observer see the countdown ETA for bus?
- Did five minute ETA reminder vibrate the phone?
- Did "Now Arriving" message show within 2 minutes of bus arrival? If not, how much time was left on the ETA or how late was the bus?
- Was the Route Number displayed on the phone?
- Did the participant successfully board the bus?
- Did TAD give the "Get Ready" notification at the correct time?
- Did TAD give the "Pull the Cord Now" notification at the correct time?
- Did the participant request the stop at the correct time?
- Did the participant exit the bus at the correct stop?

The following text describes some of comments noted from one of the testing sessions:

> *CASE STUDY 1: The participant and observer were ready to leave the University Area Transit Center (UATC) at 3:35pm, and TAD said a bus was leaving in 12 minutes. It gave the warning vibrate, then went into "Now Arriving" mode, however the bus never arrived. After displaying Now Arriving for about 5-10 minutes, TAD switched to the next bus, which was suppose to arrive in another 8 minutes. The bus had arrived with an ETA of 6:30 on the phone, and we ended up leaving when the ETA said 4:30.*
>
> *The participant seemed to have problems understanding the "Get ready" audio message played back over the cell phone. The observer noted that this may be due to the quality of the phone's speaker or the quality*

of the audio file, especially in relationship to the amount of noise present on the bus. The participant was able to pull the cord at the correct time, exit the bus and the participant waited at the next bus stop.

On the return trip, the bus arrived about 1:30 ETA (the "Now Arriving" message was shown on the phone, so the observer approximated).

Additional field testing to evaluate the TAD proof-of-concept in terms of delivering the "Get Ready" and "Pull the Cord Now" alerts at the correct time was conducted during the initial TAD prototype development and is reported in existing literature *(Barbeau et al, 2009) (Barbeau et al, 2008).* Therefore, the discussion in this paper focuses primarily on AVL integration issues with the TAD system.

5 LESSONS LEARNED AND RECOMMENDATIONS

Valuable experiences and lessons were learned during the implementation of this project which can be useful to future implementers of such systems. Many of these lessons can also be applied to the general design and deployment of other Intelligent Transportation Systems (ITS) projects within the transit environment other modes. Below, the lessons learned are divided according to the different stakeholders in designing and implementing an ITS project.

5.1 Lessons Learned for Transit Agencies: Exposing Transit Data – System Designs

There are several types of data that a transit agency may be interested in providing to external entities. Common types of exposed transit data include schedule, route, stop, and trip (combination of stops, route, and schedule) data. Real-time vehicle location and ETA information (based on real-time vehicle location data). Often, this data is provided to inform customers of general information about the transit system (e.g. schedules, bus stop locations) or to provide them dynamic real-time information about the current state of the system (e.g. bus location or estimated arrival time, etc.). Transit agencies, together with transit IT vendors, are primarily responsible for implementing the information systems that expose transit data to external systems. Typically, each transit agency utilizes proprietary scheduling software packages such as Trapeze™ and HASTUS to manage their information internally for operations purposes.

For static information that does not frequently change in real-time (e.g. schedules, routes, stops, etc.), the GTFS has emerged as a defacto standard with over 417 transit agencies placing their data into this format worldwide and over 110 transit agencies participating in the United States. The TAD system utilizes GTFS data feeds from transit agencies to import new agencies and update the bus stop and route information for existing agencies.

For real-time dynamic information access, the information system must be modified in order to make information available to external applications. Typically, this is done by either directly exposing the database (e.g. SQL Server, Oracle) containing the information or creating an intermediate application hosted on a web server, which is positioned in between the external application and the transit agency database.

Most mobile devices, including the popular Java Micro Edition, Google Android, and Apple iPhone, cannot access database engines directly since drivers to connect to the database do not exist on mobile platforms. Therefore, from a mobile application design perspective, it is highly preferred to expose the data via a web service hosted on the transit agency's web server. This allows the mobile device to contact the transit agency's system directly, without having to use a proxy server hosted at another location. When timeliness of the transit agency data is important, as is the case with real-time vehicle positions and estimated time until arrival information, having direct access from a mobile device to the transit agency's real-time data is crucial for reducing the time between when the data is generated at the transit agency to when it is made available to the mobile device. The overhead for the mobile application developer is also reduced in the web service model, since the mobile application developer is not responsible for duplicating transit information on their back-end servers. The use of web services from mobile phones is discussed in detail in the Mobile Phone Developer section.

A third architecture is required when near-real-time information updates, such as a mobile phone depending on AVL updates to alert the user when to exit the vehicle. In this third architecture, the transit agency maintains subscription information between transit vehicles and mobile devices and "pushes" information updates to the device as they are generated from within the transit agency's IT system. By pushing the information, instead of requiring the mobile device to repeatedly poll and "pull" information from the transit ITS system, real-time information is available at the mobile device as soon as possible. The implementation of such a subscription-based system is significantly more complex than a simple web service that responds to individual requests from external systems. This additional timeliness will likely be of interest to consumers of ITS information in the near future, especially for mobile devices that may not have their own embedded GPS receiver. For many current transit IT systems, the bandwidth between the vehicles (where location information is usually calculated using technologies such as GPS), and the transit IT center is constrained, preventing frequent second-by-second updates of vehicle position data. In such constrained systems, updates of location data from transit vehicles normally occur at a higher interval such as once per minute. Without a high frequency of vehicle position updates (e.g. in the order of seconds), the relative improvements in timeliness of delivering the data via a "push" to the mobile device do not justify the complexity of the implementation of the third architecture. Therefore, since HART's system is constrained to vehicle position updates around once per minute, the research team focused primarily on the first two architectures described above.

The TCIP released by APTA in 2006 covers many different use cases and standards of transferring transit information from one entity to another for both static and dynamic information *(APTA, 2006)*. Currently, there are no operational implementations of TCIP interfaces in the U.S. *(Transportation Research Board, 2009)* although a TRB Transit IDEA program is currently underway to attempt a proof-of-concept implementation in Orlando, Florida at LYNX. Other implementations are currently in the design or development stages at King County Metro in Seattle, Washington, MTA in Maryland, and Chicago Transit Authority *(Ayers, 2009)*. Since this project made use of existing data sources that do not implement the TCIP standard as part of this system prototype (e.g. AVL web service and database, GTFS *(Google, Inc. 2009)*), making TAD TCIP-compliant would not result in a working prototype. However, it is planned that, in future TAD software implementations that will interface with TCIP-compliant systems (e.g. different AVL systems), a TCIP-interpreter will be developed that will allow seamless interaction of the TAD system with TCIP-compliant systems.

The current architecture used to connect HART's system and the TAD system is shown in Figure 2. This system is an adaptation of the above two architectures to fit HART's specific method of exposing information to external systems. HART exposes vehicle position updates through direct access to a replicated version of their SQL Server database server. To show the vehicle positions on the TAD website, the TAD Glassfish Java web application server contacts HART's database server directly using Java Database Connectivity (JDBC) drivers. The vehicle positions are then pulled back to the TAD server, which passes them to the web browser client to be displayed to the TAD website user on a map. Vehicle position data is not provided to the TAD mobile phone application, since in its current design it does not have a visual map upon which to show the information. The total transfer time for GPS data to propagate from the HART vehicle until it was exposed in the replicated SQL-Server database for TAD system access was approximately 90 seconds, on average.

HART exposes estimated vehicle arrival times via a web service. This web service is implemented using both XML-based SOAP web services and a RESTful web service using HTTP-POST and HTTP-GET methods. The TAD mobile phone application uses the RESTful web service to directly request the ETA of the bus from the transit IT system then displays it to the transit riders on their cell phone screen. For access from mobile devices RESTful web services are preferred than SOAP XML-based web services due to issues surrounding the limited support of SOAP on mobile devices and the negative impact of the XML overhead on mobile device battery life, see the Mobile Application Developer section below.) Since the web service pulls information directly from HART's production SQL Server database, the response time between ETA changes when updated vehicle positions are much shorter. In other words, changes in ETA values were updated as frequently as every 15 seconds when observed by the research team. It is expected that external systems accessing IT systems at other transit agencies may have to use this hybrid approach as well, depending on the order of implementation of different ITS services, and the level of coordination and time delay between the projects implementing the ITS services. However, the implementation of these ITS systems separately can have its challenges.

One challenge faced by the research team when using the ETA web service was data consistency between the HART ETA web service and HART's GTFS data. HART formats their transit data into the GTFS file format and posts a zip file containing this information on their website. The TAD system then downloads this zip file, extracts the files, and imports the latest bus stop, schedule, route, and trip information into the TAD database. This same process is followed for all agencies that put their data into the GTFS format and are users of the TAD system. The GTFS data specification allows an agency to add directional information for trips (i.e., an ordered visitation of stops on a route at a particular time) in their dataset. However, the GTFS format requires that each trip specify the directional information as either outbound/inbound with a value of 0 or 1, respectively. Therefore, when HART's data is imported into the TAD database, it contains 0 or 1 directional information. HART's web service is designed to return vehicle ETA information when an external system inputs a stop ID, route ID, and direction ID. However, HART's web service requires that directional information be provided as North/South/East/West with the values of 1, 2, 3, or 4, respectively. Therefore, there is no information which directly connects the concept of trip direction in GTFS data and HART's web service, which prohibits a web application from retrieving the estimated arrival time for a specific direction at a bus stop. In other words, the TAD system cannot knows if a "Route X – Outbound" which was selected by the TAD website user when planning their trip is equivalent to "Route X – North," "Route X – South," "Route X – East," or "Route X – West," which are the only formats for direction understood by the HART ETA web service.

The research team implemented a work-around to query the web service for each direction until a value is returned by the web service. This works correctly for normal bus stops that are only visited by a bus in one direction (e.g. one side of the street), but if there are multiple buses arriving at a bus stop from multiple directions (e.g. transit center), there is no guarantee that the correct arrival information will be shown to the end user. The research team is currently working with HART to update their GTFS dataset to include cardinal direction information as well as the ETA web service vendor to add the capability to query the ETA information by using the GTFS inbound/outbound directional information. During testing as part of this project, some arrival times returned by HART's web service were significantly different than the actual bus arrival, up to around 20 minutes difference. Many of these errors occurred at transit centers or at bus stops that are visited by buses on the same route in two different directions. However, often the ETA times returned by HART were accurate to within about 30 seconds of the actual arrival. The true accuracy of the system will only be apparent after the above issues are resolved to ensure that the ETA for the proper bus stop and route is always returned to the cell phone.

5.2 Lessons Learned for Mobile Application Developers

Battery life is key consideration for any mobile application, particularly where the application is running in the background and using energy-intensive features. When wireless communication is involved, battery life can be significantly impacted since each wireless data transmission consumes battery energy. For example, a transit rider might wait for extended times for a bus to arrive and wants to receive continuous updates on the status of the bus. If the phone is continuously refreshing the time of arrival information every few seconds by communicating with a server, the battery life will be drained quickly. If the bus is several minutes or more away, this high frequency of updates is unnecessary and needlessly wastes battery power.

To demonstrate the impact of the frequency of wireless data transmissions on the battery life of a mobile device, a benchmarking application was developed by the research team. This application measures how long the phone battery lasts while wireless transmissions are repeated at fixed intervals. By comparing the resulting battery life from each execution, the energy cost for each transmission at the given interval is apparent. Figure 5 shows the impact of wireless transmission interval on the battery life of a Motorola i580 cell phone on the Sprint-Nextel iDEN network. Using HTTP-POST method to request the information from a RESTful web service every 4 seconds, battery life is approximately 9.5 hours. When the exact same information is transferred every 15 seconds, battery life nearly doubles to almost 18 hours. The trend continues as the time between wireless data transmissions increases, with battery life increasing to over 24 hours when data is transmitted every 60 seconds. It should be noted that during these tests no other normal cell phone operations (e.g. voice calls, lighted display screen, etc.) were active. Therefore, during the actual use of the phone with these additional activities the battery life would be reduced even further.

As demonstrated by these results, even small reductions in the number of wireless data transmissions can positively impact mobile device battery life. Intelligent systems should be designed to periodically refresh information while dynamically varying the refresh rate depending on the timeliness of the information. For example, if there is an estimated 10 minutes until a bus will arrive, the phone doesn't need to request an update for at least several minutes. Similarly, if a bus is expected in less than a minute, then the phone should request updates at a more frequent pace until the vehicle arrives, at which time it should reduce the frequency of updates again. The TAD mobile phone software implements such an intelligent algorithm in order to provide timely updates but maximize battery life.

Most cell phone platforms (e.g. Java Micro Edition, Google Android) do not directly support XML-based SOAP web services. SOAP is an XML-based protocol for exchanges messages between a web service and client. SOAP usually implemented on top of the HTTP protocol. Alternatively, RESTful web services are usually implemented directly using HTTP method such as GET and POST, and therefore have far less communication overhead than the same exact web service implemented using SOAP. Therefore, for mobile application it is preferred to use simple RESTful web services that utilize the widely-supported HTTP protocol directly without the need for an XML SOAP parser on the mobile device. For parsing XML-based responses (e.g. transit information), which may be returned by RESTful web services, kXML is a good open-source library for basic XML parsing of message content *(kXML, 2009).*

From an energy-use perspective, XML-based SOAP web services should be avoided when possible by mobile applications. The XML tags add significant overhead to the message, resulting in a greater energy loss as the radio must be active for a longer period of time. Additionally, in wireless environments where interference is common, the probability that a message will be corrupted and must be re-transmitted increases as the length of the message increases. At 60-second transmission intervals, battery life when using JAX-RPC is 19.3 hours and batter life when using HTTP POST is over 24 hours. Similar results are found at lower interval values, thus justifying the choice of HTTP POST over JAX-RPC as the more energy-efficient application-layer communications protocol.

It may be possible to implement additional TAD features (e.g. using vehicle position as a substitute for phone position when phone positioning system fails) by interfacing with other AVL system implementations that have the wireless bandwidth required to support more frequent vehicle position updates from the vehicle to the TAD system. As frequency of vehicle updates increases to approximately once every 20 seconds and approaches true real-time, UDP should be used to send real-time vehicle position to phones instead of the phone continuously requesting position from server via a protocol such as HTTP. Typically, cell phones are not provisioned for "push" data services, and therefore they will need to be provisioned with the correct data plans to make sure they can receive UDP datagrams. Some cell phone networks are packaging publically addressable IP addresses with unlimited data plans, so this type of service may be available on most phones with unlimited data plans.

For location capabilities on the Java Micro Edition (Java ME) platform, the JSR179 Location API is the primary source of real-time GPS information *(Sun Microsystems, Inc. 2007).* Version 2.0 of this API, JSR293 Location API 2.0, was finalized in November 2008 and should appear on commercially available handsets in 2010 *(Sun Microsystems, Inc. 2009).* The LandmarkExchange formats defined in Location API 2.0 will allow the easy exchange of "landmark" information between a cell phone and another entity (e.g. server or phone). It is recommended that mobile developers understand the abilities of this new API and take advantage of landmark datasets, such as transit bus stop inventories, that could easily be imported to a mobile device through these formats *(Barbeau et al., 2008).*

During frequent software revisions, the ability to "replay" existing recorded trips through the TAD software using the emulator proved to be very valuable. When trips are tested by traveling on the bus with TAD software running on the cell phone, the GPS data observed by the device during that trip is automatically saved to the TAD server database. Using the export tool developed as part of this project, this GPS data can be exported to an XML format that can be loaded into software emulators that run on desktop PCs for future testing. This process saves a significant amount of time when debugging software or testing a new software revision for stability before actually spending the time in the field to go on a bus trip. Because of the uncertainty associated with GPS, there is still no substitute for evaluating the performance of location-based applications using a real cell phone and actual field testing in the environment in which the mobile application will be operated. When evaluating the performance of new transit rider notification algorithm actual bus trips were tested. It is only during real field tests that the potential accuracy and reliability of the system can be properly evaluated. Readers interested in a more thorough evaluation and discussion of the TAD's ability to alert the transit rider to request a stop at the appropriate time are directed to existing literature discussing Phase 1 field tests *(Barbeau et al, 2009) (Barbeau et al, 2008).*

In the future, a Bluetooth headset will be investigated as a possible delivery tool for the audio prompts. In these field tests, one of the participants seemed to have trouble understanding the "Get Ready…" audio alert due to background noise on the bus. Utilizing a Bluetooth headset should help avoid some of this noise interference and deliver the audible alerts clearly.

5.3 Lessons Learned for Researchers: Field Test Participant Recruitment and Training

One significant delay associated with this project came in the process of recruiting and testing the TAD system with individuals with special needs to produce case studies. The research team attempted to recruit six individuals with cognitive disabilities to participate in the field tests as part of this project. Successful recruitment was difficult over the summer due to summer vacations and limited communication with participants. Field testing was therefore completed with three cognitively disabled individuals. For future tests, additional time throughout the year should be allowed for the recruitment and field testing process. The initial TAD prototype was evaluated by individuals with cognitively disabilities during system development, and the discussion of these tests can be found in the TAD Phase 1 final report *(Barbeau et al, 2009) (Barbeau et al, 2008).*

Overall, the research teams experience with individuals that have tested the TAD mobile application, and anecdotal information from travel trainers and special education professionals, has indicated that a typical "flip-phone" cell phone with the TAD mobile application installed is not a problem for the majority of users to operate. In fact, many individuals with special needs that travel without supervision already carry phones so that their parents or caretaker can communicate with them in case of emergency. The TAD cell phone application has only three simple screens: a screen to select a trip by name (e.g. "To Work") which has been previously planned for the user via the TAD website, a screen which shows the ETA to the rider while they are waiting for the bus as well as a distance count-down as the rider travels on the bus, and a screen shown to the user when it is time for them to request their stop. HART's travel trainer that lead orientation of TAD with participants stated that it took no more than 5 minutes to give a basic explanation of how to use the TAD mobile application and what to do when it prompted them to "Get Ready…" and "Pull the Cord Now!" Each trainee that heard the announced alerts responded positively to the prompts and requested the stop as directed during the tests. The trip planning portion of TAD is conducted using a website, and this step would most likely be executed by a travel trainer or parent/care taker for individuals with cognitive disabilities since it requires higher-level planning. Trip planning could be conducted by the transit rider if the individual is capable of completing the tasks required to successfully plan a trip. The research team is also currently examining website technologies that may be useful to aid visually impaired individuals in independently planning a trip via the TAD website. Future work with the Florida Mental Health Institute at USF is also planned to provide a more thorough human behavior analysis of the impact of TAD on transit riders with cognitive disabilities.

A demo TAD application should also be developed that could be used to demonstrate what the transit rider is expected to hear and see before the participant boards the bus. Currently, the device actions were verbally explained to the participant before the test but no demonstration of the actual device actions were performed. This could avoid some lack of understanding for certain issues, such as the participant who could not understand the audible "Get Ready…" announcement, because the participant would know what to expect.

5 CONCLUSIONS

In order to assist transit riders in the navigation of the transit system, Travel Assistance Device software for GPS-enabled mobile phones can give them personalized tactile, visual, and auditory prompts such as "Get Ready.." and "Pull the Cord Now!" in real-time. The integration of AVL technology with the TAD system was successfully demonstrated through proof-of-concept testing. TAD shows the estimated time to arrival of bus while patrons are waiting at their bus stop. Additionally, the real-time vehicle locations are shown on the map on the TAD website. Because both of these features are driven by the GPS location of the cell phone and bus, the rider does not have to supply any additional information such as a bus stop ID or route number in order to receive that information. While TAD was initially created to help the cognitively impaired, any rider can benefit from the TAD service. Obvious examples are tourists, new riders, or occasional riders. The feature that displays minutes and seconds counting down until bus arrives is valuable to all riders since it reduces the anxiety associated with waiting. USF is actively pursuing the licensing of the TAD technology and hopes to offer TAD as a nationwide commercial service within the next year.

Many lessons were learned during the implementation of this project. First, when designing components of transit IT systems, the vendor and agency should work together to ensure that all datasets produced by the agency can be interconnected through common attribute values (e.g. direction always represented as "outbound/inbound") and the same unique identifiers. Second, lightweight RESTful web services are preferred to XML-based SOAP implementations for exposing transit data to external systems due to the lack of SOAP support on mobile device platforms and the negative impact of the additional overhead from XML on mobile device battery life. Finally, further consideration should be given by the transit industry towards standardizing web service design for exposing real-time transit information. Currently, there is no widely-accepted standard for exposing real-time transit information via a simple light-weight (e.g. RESTful) interface that is practical for mobile devices. The TCIP standard should be consulted during this process. Even though currently planned implementations of TCIP appears to be heavily oriented towards the use of XML, some of the design principles used to create TCIP should be useful in determining a common format for querying and retrieving real-time transit info from transit agencies' IT systems.

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LIST OF TABLES AND FIGURES (in order of appearance in text)

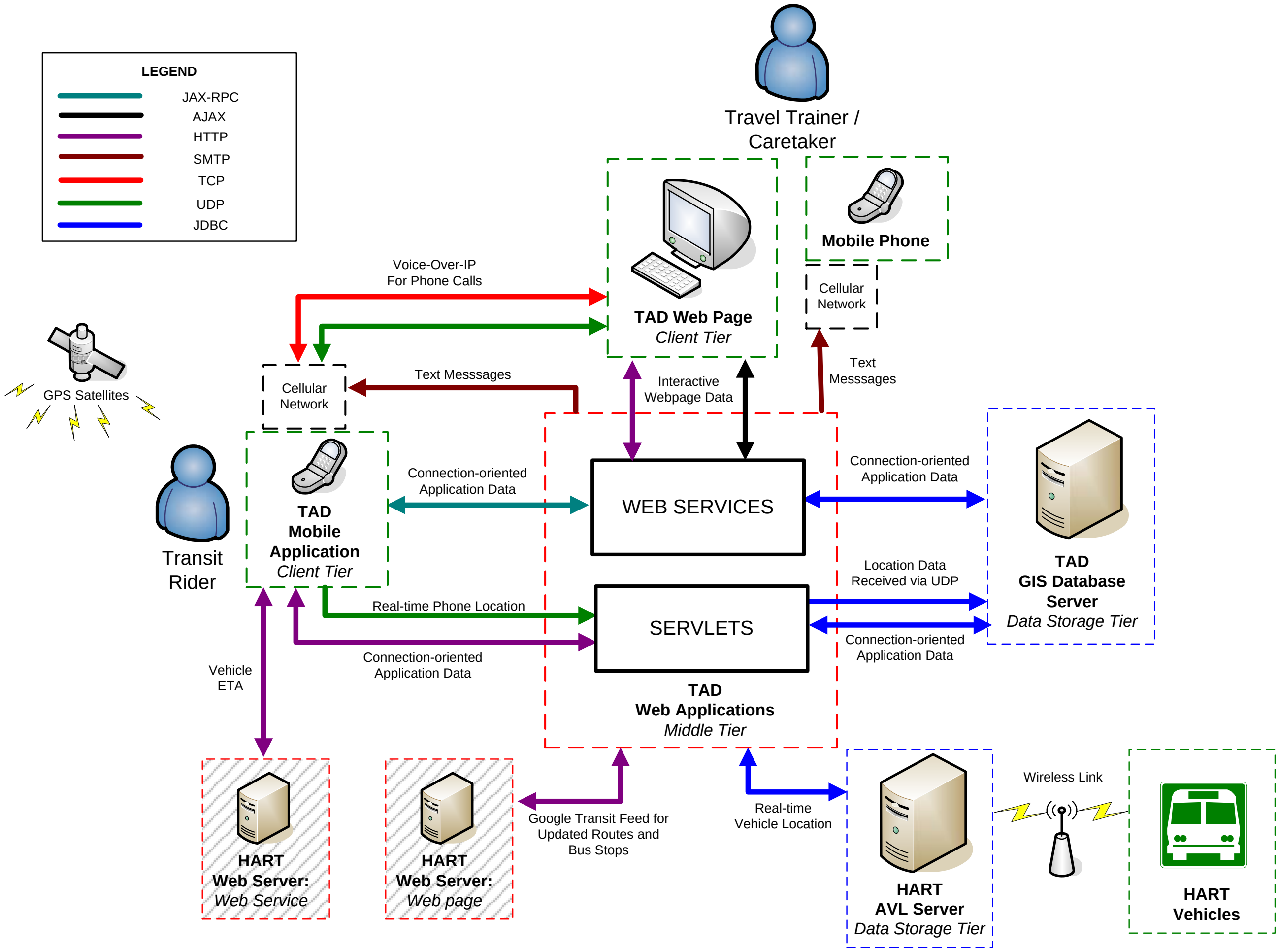

FIGURE 1 – Travel Assistance Device complete architecture.

Requirement	TAD's Functionality
Display the remaining wait time for the transit rider while they are waiting for their proper bus to arrive at the stop.	Utilizing the information from HART's web service and knowledge of the user's planned route, the TAD system will query HART's web service for the estimated time of arrival for the correct stop and route and display the information on the phone's screen.
Alert the transit rider when the correct bus approaches to board is approaching his or her bus stop location	Utilizing the information from HART's web service and knowledge of the user's planned route, the TAD system will query HART's web service for the estimated time of arrival for the correct stop and route and alert the transit rider when the estimated time until arrival is less than a threshold value.
TAD Web page shows real-time bus locations	By combining current active service information stored in TAD database and bus location data stored in HART AVL data source, the webpage will display locations of the buses on the TAD Web Page.
New notification algorithm for TAD mobile application to benefit the rider	By using the current speed of the bus and several circles of different radii around the second-to-last bus stop, the TAD phone software will determine the earliest appropriate time it can trigger the alert to the user to pull the cord. The goal is to sound the alert right after passing the second-to-last bus stop so that there is less confusion for the rider. The previous notification algorithm worked well when stops were a significant distance apart, but had challenges providing the notification at the correct time when bus stops were close together. The new algorithm attempts to overcome this limitation.

TABLE 1 – Travel Assistance Device Functionality Requirements

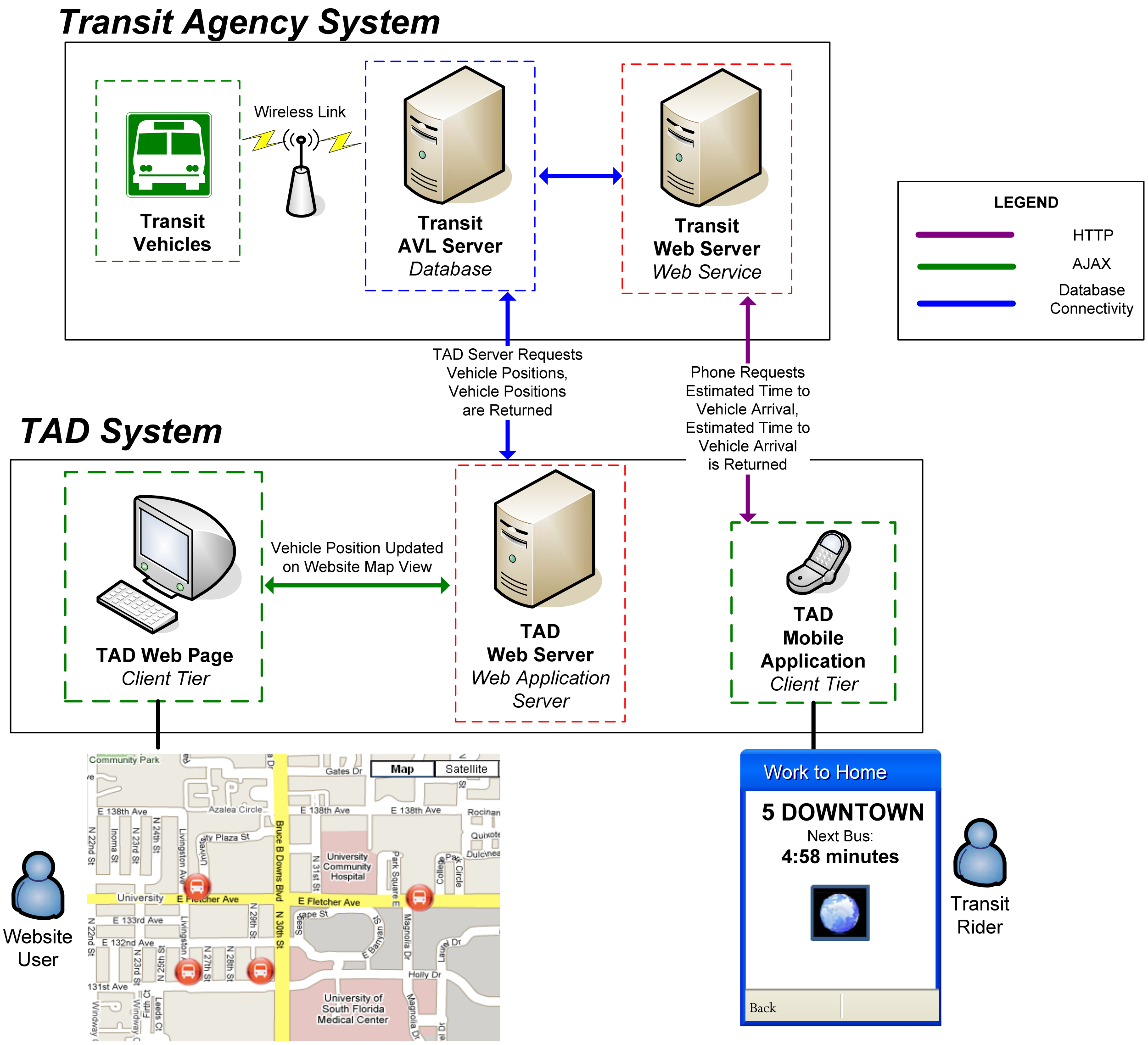

FIGURE 2 – TAD interactions with HART AVL system components.

FIGURE 3 – After selecting a trip, the user is shown real-time vehicle estimated time until arrival.

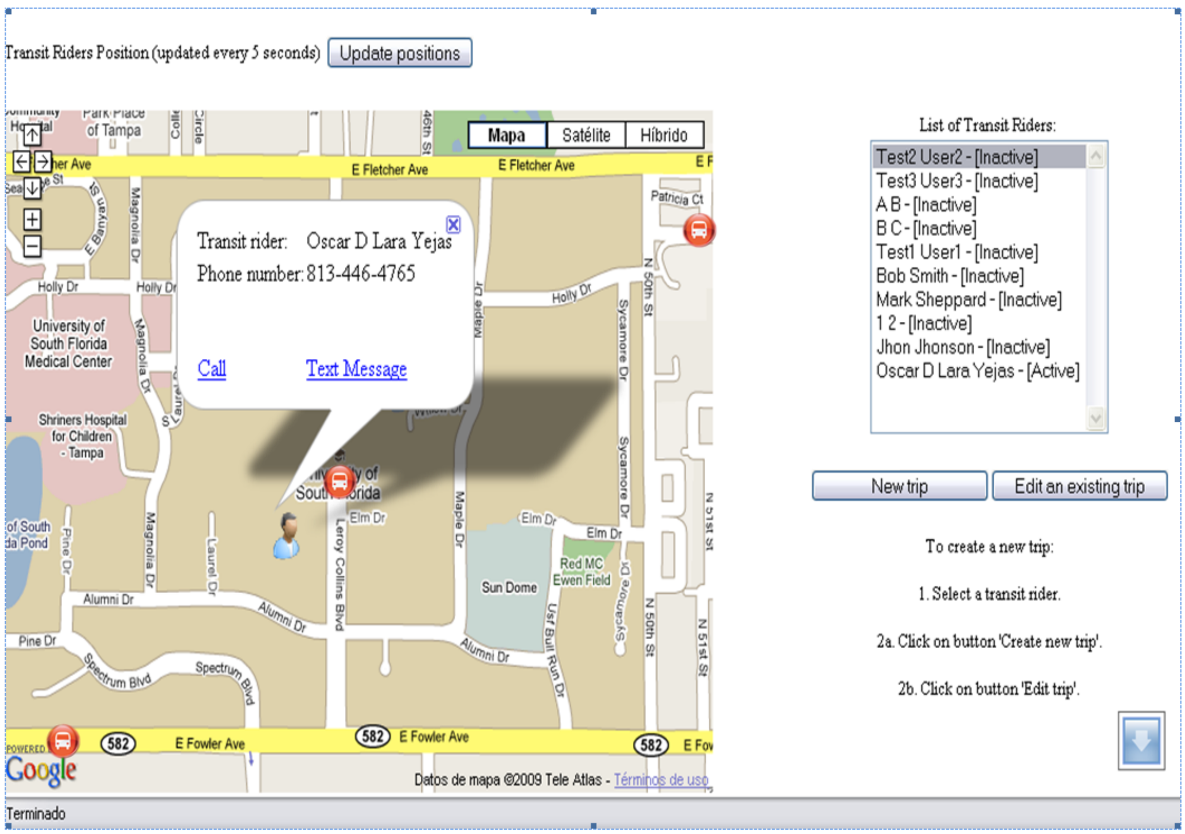

FIGURE 4 – Tracking screen of TAD web page showing real-time bus locations and rider position for travel trainer

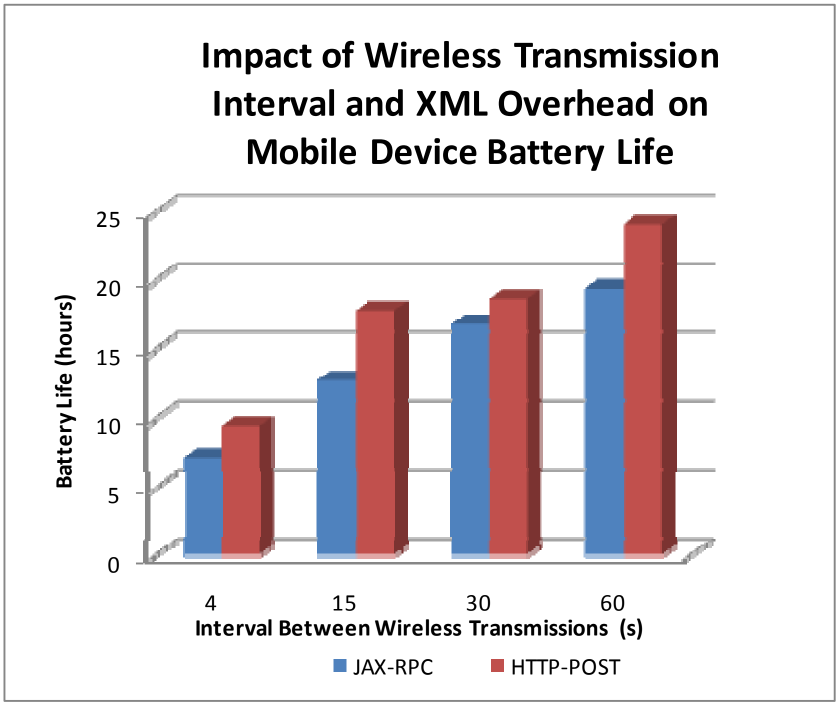

FIGURE 5 – The impact of wireless transmission interval and XML overhead on mobile device battery life