RFID TECHNOLOGY FOR AVI: FIELD DEMONSTRATION OF A WIRELESS SOLAR POWERED E-ZPASS® TAG READER

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ABSTRACT

This paper reports on a field demonstration of RFID tag reading technology designed to collect link travel times for traffic management. Multiple wireless solar powered E-ZPass tag readers were deployed and tested at two locations in upstate New York. The technology developed is described, as well as illustrated examples of the data collected and presented in real-time via the internet. A prognosis for deployment of technology for use at special events and work zones is also given in this paper.

Key words: ETTM, wireless, E-ZPass tag reader, RFID, travel time, arterial data collection.

INTRODUCTION

RFID technology has been proposed as a viable means of observing traffic as part of an AVI system. To date, many of the deployments of the technology have been using fixed installations, typically on freeways. Some examples of this are the TRANSMIT system in New York and New Jersey and the FasTrak™ system in California. The purpose of the work described in this paper is to report on a demonstration of RFID tag reader technology in collecting link travel times where permanent installations are not practical. For example, the technology could be used for traffic management on local arterials or during special events or work zones. The next section of the paper reports on the equipment and technology developed for the demonstration followed by a description of the networks used. The following section provides an insight into the performance of the system, that is followed by examples of the data collected; the paper concludes with a prognosis for the deployment of such technology.

1 E-ZPass is a registered trade mark of the Port Authority of New York and New Jersey
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EQUIPMENT AND TECHNOLOGY

The wireless, solar powered E-ZPass tag readers were developed and deployed by RPI with Mark IV Industries as the industrial partner. This unit is comprised of Mark IV’s low powered mGate™ tag reader, antenna, solar panel, batteries and charger, enclosure and a pocket PC (PPC). A schematic of the system can be seen in Figure 1. This section describes the system in more detail.

The mGate reader is about the size of a shoe box and power consumption is approximately 6 watts. Each mGate can receive inputs from up to two antennas connected via coaxial cable, operating in the 915 MHz frequency band. To minimize RF signal loss, the length of this cable was kept to a minimum. This reader also has three output connections, one for connection to the host and the others for separate lane controller applications.

The system contains one 120 watt solar panel and two 100 amp-hour batteries for storage. Also included with the solar components are a charger and circuitry to protect against surges and brownouts. This configuration is capable of supplying power to the mGate for 8 - 10 days, even if no sunlight was present. To protect the components from weather and vandalism, a locked NEMA field cabinet was used. A view of the interior of the cabinet can be seen in Figure 2.
When the device was first built, a laptop was used as the communication device. The laptop was stored in the cabinet and connected to the mGate reader via a RS232 serial cable. When the laptop was charging, the power consumption was found to be approximately 65 watts. This system was not designed to power the laptop; using a pocket PC (PPC) as an alternative communication device was quickly investigated. Field testing indicated that the power consumption of a PPC was approximately 5 watts. The solar components were not designed to power anything except for the mGate reader. Therefore, connecting the PPC and other devices to the power system was pushing the capacity of solar power generation.

The PPC used was the HTC Mogul (PPC 6800). This was the most recent model offered by Sprint at the time of deployment. This device runs on the Windows Mobile 6.0 platform, has a 400Mhz processor, 256MB ROM, 64MB of RAM, and Bluetooth 2.0.

In a typical application, the mGate reader transfers data via a RS232 serial cable to a computer. Since PPC’s do not have serial ports it was necessary to investigate other options. A serial device was found that linked the PPC to the mGate reader via a Bluetooth adapter. The Bluetooth device required an additional 5v of power. Testing indicated that the power consumption with the PPC and Bluetooth combination was tolerable for the solar power system. In addition, testing indicated there was no interference with the mGate reader.

The PPC’s encrypted the data in the field and uploaded this secure data to a central server in real time for processing. The encryption algorithm enabled each tag to be securely tracked from reader to reader without compromising any personal information.

All the equipment was mounting to a trailer with a mast as shown in Figure 3. The mast could be rotated 360 degrees and was used to raise the antennas to the proper height and mounting angle, which was a critical parameter in order to achieve performance. The antenna was mounted to a pan tilt motor which allowed the team to adjust the placement of the antenna without lowering the mast. This feature made the deployment of the devices much faster. The time it took to setup the trailer from when it was dropped at the site until the device was fully functional and transmitting data was typically in the range of 20 – 30 minutes.
It should be noted that obtaining permission to deploy these devices alongside of the road created problems. First a set of sites that could be used for useful data collection had to be identified. In addition to checking for field constraints such as overhead wires or ditches, setback guidelines had to be checked. The AASHTO Green Book: A Policy on Geometric Design of Highways and Streets suggest that a fixed object should be placed a certain distance from the roadway (2). This distance is dependent on several factors, such as the design speed and curvature. Once the DOT granted permission for the sites, the landowners had to be asked for permission. Lastly, proper licensing from the Federal Communications Commission (FCC) was obtained for each site.

Due to the horizontal clearance requirements not all of the devices could be setup on the trailer as shown in Figure 3. Instead the trailer was parked in the clear zone and the antenna was attached to a road sign and a coaxial cable was run to connect to the two. An example mount can be seen in Figure 4. At first there was concern that if these break-away structures were hit by a vehicle they may not perform as they were designed. The National Cooperative Highway Research Program (NCHRP) published Report 350, Recommended Procedures for the Safety Performance Evaluation of Highway Features, which deals safety performance of such devices (3). One concern FHWA had with this was to make sure the antenna was at least 9’ above the roadway so it would not penetrate a windshield if struck by a vehicle. In most cases the team found existing sign locations that were behind guiderail or on steep embankments; this was to help reduce the possibility of damage to a vehicle if it were struck. It should be noted that in these cases longer RF cable would be needed and longer cabling distance reduces the reader's range to read tags.

The following section discusses in more detail the findings from the various tests that were conducted.

**NETWORK AND DATA COLLECTION PROCESS**

The RFID tag data was collected to monitor traffic on the US Route 4 corridor in North Greenbush, NY. Route 4 is a two lanearterial serving a community college and technology park.

Six of the wireless solar powered tag readers were deployed from July 2007 until early 2008 at the locations shown in Figure 5. Most of the testing was conducted in the Rensselaer ITS testbed. These devices were also deployed in conjunction with the NYS Fair in Syracuse, NY to monitor conditions in and around a nearby work zone. Link travel time data was gathered from these solar powered wireless tag readers and transmitted in real time to the web.
Traditionally, antennas for tag readers are installed directly over the travel lane (overhead). As part of this project, the reader’s antenna was installed at the side of the road, in a side-fire configuration. In most of the installations the reader was deployed on the shoulder of the road, resulting in the traffic from only one lane being captured. In one case it was possible to deploy the reader on a center median island and it captured traffic in both directions.

Tag data was recorded every time a vehicle with an E-ZPass tag passed by a tag reader. During the experiment it was found that on the local arterials in New York State’s Capital District, the percentage of vehicles with E-ZPass typically ranged between 22.5% and 30%. While deployed at the NYS Fair, the tag percentage on the arterials and local streets was measured to be at least 25% and as high as 35% on the interstate. By comparison, according to IBTTA (International Bridge, Tunnel and Turnpike Association) survey statistics for 2006, New York State Thruway toll facilities have an average tag penetration rate of 59% and as much as 83% at peak (1).

In addition to the encrypted tag ID, reader ID and time stamp, reader diagnostic data was collected. This data included battery health of the PPC and vehicle class as indicated on the tag. This data was sent in real-time to a central server where travel time information was processed and sent to a private, secure application accessed by the World Wide Web. This application has the ability to show a user-defined period of time and shows average travel times and speeds between two reader locations. This report displays pairs of readers that have recorded identical tags, with the starting point on the left and the end point on the right. Again each reader displays
its most recent read, current battery life and sum of tags scanned over the reporting period. In addition, each pair reports the distance between them, the average travel time, average vehicle speed, and the number of matched tags that were included in the analysis of those two points.

<table>
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<th>LAST READ</th>
<th>STATION ETTM_6</th>
<th>STATION ETTM_1</th>
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<td>NORMAL TRAVEL SPEED</td>
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<tr>
<td># RECORDS INCLUDED IN ANALYSIS</td>
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<tr>
<td># RECORDS INCLUDED IN ANALYSIS</td>
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Figure 6 Sample travel time data displayed on web

The travel time and speed between points is averaged, and thresholds are defined for each pair of points that represent maximum travel time that a matched pair qualifies for. Scans that exceed that threshold are not included in the analysis but are logged in the master database. A sample set of the travel times posted to the web can be seen in Figure 6. The figure shows two sets of travel times. The first one is between devices ETTM_6 to ETTM_1 which is the southbound movement on US Route 4 to the Rensselaer Tech Park; the second set of travel time data is between ETTM_6 and ETTM_3 which is the through southbound movement on US Route 4.

DEVICE PERFORMANCE

Six of the devices were deployed along US Route 4 in North Greenbush, New York in July and August 2007 and again from October 2007 until January 2008. These deployments served mainly as a system evaluation, whereas the testing in late August 2007 at the NYS Fair served as a deployment at a real work zone and special event for monitoring travel times. With the Route 4 testing the team was fortunate enough to have the readers deployed during all types of weather conditions such as hot humid days, severe rain and wind as well as snow and ice.

The antenna deployments along US Route 4 were a combination of both trailer mounted and sign mounted as discussed earlier. Once the optimal antenna height and angle was achieved in the field the system performed quite well for both types of deployments. Manual field counts were taken often at each of the readers to check the tag read reliability of the device. When the device was on it was found that in most of the cases for the trailer mounted antenna the reliability was between 90 – 95% capture of the tags in the detection zone. The sign mounted antenna also
performed with similar results. The most limiting factor had to do with the antennas proximity to the roadway and the number of lanes being captured. For example, one of the sign mounted sites only captured approximately 55 – 65% of the tag equipped vehicles passing by. The cause for this was not faulty equipment but rather a flared travel lane where vehicles normally drove further away from the shoulder of the road. The team also believes that a fair number of the tags that were not read by the device were external factors such as improper tag placement within the vehicle.

Most all of the components that comprise the system were found to be durable during the field evaluation. There were a few failures due to condensation damaging the coaxial components but these were relatively rare and with the proper weatherproofing eliminated. Besides holding true for rain it was also true for ice and snow.

The most problematic component of the system was the communication device. The PPC that was used claimed to be one of the more advanced devices on the market at the time of deployment. However, the PPC was the result of most of the failures while the system was deployed. It is unfortunate but there was no way to log the reasons for failure on the device; in many of the cases the PPC would just shut down during operation. The team was fortunate enough to have the ability to view the web application and see the last tag transaction for each of the readers. If there were no recent tag reads then the team could go to the field and reset the necessary devices. The PPC vendor was aware of the problems and during the course of the seven month test four ROM updates were released to try and fix the problems. One of the updates was quickly recalled and the vendor told the users to reinstall an older version of the software. The primary failures with the PPC included Bluetooth instability between the PPC and Bluetooth serial adapter, insufficient operating memory and in a few cases some random failures with the custom encryption software.

Since the PPC did not have any ports that would allow for a hard wired connection to the mGate reader it was necessary to use an AIRCable Serial Bluetooth adapter. The Bluetooth device was unique in that you plugged in the mGate RS232 cable and the device transmitted the data to the PPC via Bluetooth. The communications between the PPC, Bluetooth device and mGate reader would sometimes terminate at random, with no predictability as to when it might occur between these two devices. In some cases the devices would stay connected for over 200 hours, while in other cases it would terminate after a few tag transactions or in some cases not connect at all. Since there was no way to log each type of failure only an estimate can be made. It is estimated that the PPC Bluetooth failures accounted for at least half of the total failures of the device.

Figure 7 shows the frequency of the failures by month for all six of the tag readers. The x-axis is the consecutive hours the device remained operational without intervention. The most frequent length of time the devices would stay operational was between eight and ten hours.
When the system was designed it was not built to power any type of communication device. This was because the original plan was to test the tag reader and its components and see how well it would function when powered by a solar panel. The team then decided to push the envelope and see how it would function in a 24/7 environment while providing power to the PPC and Bluetooth adapter. The system was able to power all the components for much of the study even during cloudy days. The period from late November until mid January in our region proved to be the most problematic for the solar components. This was because it was the time leading to and from the shortest day of the year and many of the days were cloudy without any sunshine. Many of these failures accounted for the high frequency of failures after eight to ten hours as shown in Figure 7. This is because often times during that time period a team member would reset the device in the morning as the sun would rise and the device would function until the sun would set later that day. Because of the weather the solar panel could not provide enough power to store additional power in the batteries. It should be noted once again that the system was not designed to power the PPC and Bluetooth device, just the mGate reader. This extra power consumption was the main reason for the power failures. It was found that if more battery storage were available this problem would likely be resolved. In October there were the most occurrences of times when the readers remained operational for 30 to over 200 consecutive hours. The team believes that this was due to somewhat longer days and improved PPC performance due to a ROM update performed in late September.

On average the devices would operate for 38 hours before shutting down, again in most cases this was due to the PPC reliability. In some cases the PPC would only function for a few hours while in other cases it would function in excess of 200 hours. A device that consumes less power and more stable is needed to combat this issue and make the system more reliable. It should be noted that some small scale device testing was done during the summer of 2008 to test a more recent ROM update for the PPC. Although the testing was not as rigorous as the earlier field testing the results showed that the PPC was more stable when connected to the Bluetooth adapter and the connection times were much more reliable.
During the deployment at the NYS Fair in 2007 the system had to be operational between the hours of 9:00 AM and 11:00 PM at a minimum. This was because these were the hours the Fair was in operation and real-time travel time information was critical. It was found that during that time period the six devices were operational 82% of the time on average. One reader was operational only 68% of the time, while three of the readers were operational 87 to 92% of the time. Similar to the US Route 4 deployments it was found that most of the failures were related to the performance of the PPC and or the Bluetooth device.

**ILLUSTRATIVE DATA**

This section discusses the travel time data that was collected during the field deployments along US Route 4 and at the NYS Fair. The encrypted tag data was uploaded to a server and processed in real time during the experiments. The travel time information along sections of US Route 4, a local arterial, were monitored. Data collected on local arterials is normally sporadic, usually consisting of spot speeds or volume counts when data is available. Travel time information is seldom collected.

Figure 8 shows the average travel time aggregated in 15-minute intervals for a pair of readers during the length of the study. It should also be noted that the times on the PPC’s were automatically synced with the cellular network. Therefore, the travel times recorded were true point to point times. The plot shown represents the travel times between Reader 1 at Jordan Rd to Reader 5 at Route 4 NB. Vehicles making this movement must pass through two traffic lights. The figure indicates that in general the travel time between the two readers is between 1.5 and 2.5 minutes, however the peak travel time is clearly seen to be between 5:30 and 5:45 PM at 4.5 minutes. These types of variations have been monitored for each of the reader to reader pairs.
and similar trends can be seen. Also, these types of plots have been created showing the change in travel time for different days of the week and different months of the year.

The wireless, solar powered E-ZPass tag readers can also be used for incident detection. The blue line in Figure 9 shows an example of a snow storm that occurred on December 13, 2007 along the Route 4 corridor. The snow started at about 11:00 AM and at noon the parallel Interstate 787 was closed due to an accident, therefore diverting traffic from the interstate to the local arterial. The figure shows that by 1:00 PM the traffic on Route 4 reached its peak travel time. It took more than 35 minutes to go from Reader 2 to Reader 5, a distance of approximately 2.2 miles. The red line shows a typical December weekday it would take approximately 5 to 8 minutes on average to transverse the same link depending on weather conditions. The black line on the plot also shows that for a typical day in October the travel time between the same two points is usually below five minutes. Also, comparing the two typical days on the plot (red and black lines) it can be seen that many of the peaks in travel times follow the same patterns. For example, there are common peaks at 1:30 PM, 5:00 PM and at 6:45 PM. The difference is that in October they are less pronounced because the weather was less inclement than in December.

During the NYS Fair the six wireless solar powered E-ZPass tag readers were deployed. Travel time data between the various readers was published in real-time to a website. The website was made available to the NYSDOT officials so the link performance could be monitored during the Fair.
A sample of the travel time data can be seen in Figure 10, the travel times shown are between the Bear Street on ramp to I-690 then through the work zone and ending at the I-690 westbound Exit 7 entrance to one of the parking lots. This data has been aggregated into 15-minute intervals for each of the days of the Fair. It can be seen that from day to day the travel time between readers is normally two to three minutes, but in some cases the travel time increases to nearly nine minutes. The spikes in travel time do not occur at the same time each day. This type of data is beneficial to a traffic manager as the variations can be monitored in real time and acted upon if necessary.

**CONCLUSIONS**

The concept of a portable solar powered tag reader with wireless data communication capability significantly changes the equipment strategy for traffic monitoring applications. The lower cost of an mGate reader makes reader deployment feasible for traffic management, where power and communications are absent. These devices may costs as much as 75% less to install than a fixed installation and can be moved from site to site depending on the needs. There is a trade off in roadway coverage and performance when using the mGate but for traffic monitoring, the differences appear to be acceptable.

This type of reader can be used for special events such as incidents, work zones and concerts. At such events deployment time is critical and mounting to an overhead structure is not always feasible. This project proved that such a technology can function and provide useful data in real time. The design allows for deployment right from the trailer or if data from multiple travel lanes is desired, the antennas could be mounted on an overhead structure. In both instances the
solar mGate design can be quickly deployed. This type of device will be of value to a wide range of system operators, ranging from state agencies like NYS DOT to local towns and cities. E-ZPass tags are distributed by toll agencies in 13 states across the northeast and into the midwest. As of June 2008, there were more than 17 million units in service, according to the E-ZPass Interagency Group (4). Therefore DOTs and other transportation agencies across the northeast can take advantage of this concept. Since it eliminates the need for built infrastructure and the present dependence on power and wired telecommunications, the device is deployable anywhere, anytime.

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