Evaluation of Smartphone Applications to Provide Intersection Information

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Abstract

This article reports on a two-part study that examined the effectiveness of two types of technology designed to provide information and increase safety for travelers who are blind or have low vision as they prepare to make street crossings at complex signalized intersections. The project was approved by the institutional review board of North Carolina Central University. The subjects of this study consisted of 31 individuals who were blind or had low vision and who self-identified as experienced cane travelers. The first objective of this study was to evaluate a means of communicating intersection information to travelers from Bluetooth beacons to user smartphones so that they could better understand the configuration and characteristics of a complex intersection. The study identified the most critical information that should be presented through this system and obtained data on its level of importance to the traveler. The second objective of this study was to explore the use of a smartphone to initiate the walk signal at an accessible pedestrian signal (APS) and, thus, avoid the need to find and press the pedestrian button. The study evaluated the value of these smartphone applications and identified changes that would enhance their use. The results from part one of this study verified the relative importance of the information provided to subjects and established the value of a Bluetooth beacon system in providing information about the characteristics of an intersection prior to making crossings. The results from part two of this study found that the use of a smartphone to initiate the walk signal at an APS eliminated the need of the traveler to leave the crossing point to find the call button and then return. Subjects reported that, without having to turn and find the APS, they were able to maintain a direct line of approach to the corner, which allowed them to better establish alignment with the traffic prior

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to initiating a crossing. In addition, the use of a countdown timer embedded in the application provided helpful information about the time remaining during the crossing.

Introduction

Two of the important issues facing travelers who are blind or have low vision include (1) gathering enough information about the characteristics of the intersection before initiating a crossing and (2) establishing a line of direction that will result in a crossing that does not veer outside of the crosswalk lines (Bentzen et al., 2004; Fazzi & Barlow, 2017; LaGrow & Long, 2011).

Characteristics of the Intersection

While sighted individuals can casually determine the characteristics of an intersection by using their vision, the individual with visual impairment who is traveling independently does not have access to the same amount of information (Barlow et al., 2010a). When approaching an unfamiliar intersection, travelers who are blind or have low vision need to use their hearing and other sense modalities to gather essential information about the intersection. In order to make a safe crossing, among other tasks, travelers must identify the geometric configuration of the intersection, the number of lanes that they will have to cross, the presence and location of a pole with a pedestrian call button, the presence of a median strip, and the presence of a possible dedicated left-turn lane and understand the intersection traffic control timing of the traffic light (Barlow et al., 2010b; Fazzi & Barlow, 2017). These tasks are complex and, depending upon the type of traffic control, may require the individual to spend more than one traffic cycle gathering this information (Williams et al., 2005).

One approach to lessening this complexity has been to provide some of this information through a tactile map that employs a raised line diagram mounted on a pedestrian signal pole depicting the physical layout of the street to be crossed (Barlow et al., 2010a). However, this tactile layout has not been deployed in large numbers and is limited in the information provided. It also requires the individual to understand the symbolism that represents the elements of the intersection. A better solution for this problem would be to provide information about the intersection in an auditory format through an individual's smartphone (Figure 1).

Accessible Pedestrian Signal Crossings

Many intersections have actuated or semiactuated control systems that detect the presence of a vehicle and provide a vehicular movement cycle (green light) just long

Figure 1. Tactile Map of Crossing

enough to allow for the vehicle to progress through the intersection. The amount of time allocated may not be long enough for the pedestrian to complete a multilane crossing (Barlow et al., 2010b). Pedestrians who want to cross those multilane intersections often need more time for the walk cycle than is allocated by the actuated or semiactuated system. Pedestrians are, therefore, dependent upon accessible pedestrian signals (APS) to provide sufficient time for the walk phase of the cycle. For this reason, a pedestrian call button is used to extend the walk interval.

Intersections with APS require the traveler to locate the pedestrian call button on the pole that initiates the walk interval. Best practice requires the traveler who is blind or visually impaired to first locate the crossing point at the crosswalk, backtrack and find the pole that is equipped with the pedestrian call button, and then return to the crossing point (Barlow et al., 2010a; Fazzi & Barlow, 2017). The Manual on Uniform Traffic Control Devices (MUTCD) (Federal Highway Administration, 2009) and the American with Disabilities Act (2010) accessibility guidelines provide information on the positioning of APS. Guidelines state that the pole with the pedestrian button should be within 5 feet of the crosswalk line if extended and within 10 feet of the perpendicular

Figure 2. Pushbutton Location Within 5 Feet of Crosswalk

curb (Federal Highway Administration, 2009). While this is the ideal location, there are intersections where such installation is not physically possible, and the distances may be greater. Even when the poles do comply with these standards, their location still requires pedestrians to vary from their straight line of travel to find the pole. This causes difficulty as travelers must make a detour from their original trajectory and backtrack to locate and press the pedestrian push button. Sometimes it may be necessary for the traveler to return from the corner and locate the call button more than once if traffic conditions are not ideal (Figures 2 and 3).

Correct alignment at the corner prior to crossing is essential for a pedestrian who is blind to walk within the crosswalk lines and reach the destination corner. Alignment is attained by maintaining a straight line of direction to the corner and then adjusting by listening to the traffic moving on the parallel street (Hill & Ponder, 1976). Travelers project a line of travel that is parallel to the movement of the traffic. On the next walk cycle, they can then start their crossing when the parallel traffic in the lane closest to them is starting to move through the intersection (Barlow et al., 2005; Fazzi & Barlow, 2017; Scheffers & Myers, 2006).

Backtracking to the APS and returning to the corner can cause some misalignment. Travelers who have left their position to find and press the pedestrian call button, upon returning to the perpendicular street, will have made turns that may affect walking a straight-line path to the corner. Furthermore, after they have pressed the walk button and returned to the corner, the traffic light is changing, and they do not have time to reestablish alignment with the traffic (Fazzi & Barlow, 2017). If they wait extra time to listen and adjust their alignment before crossing, some of the

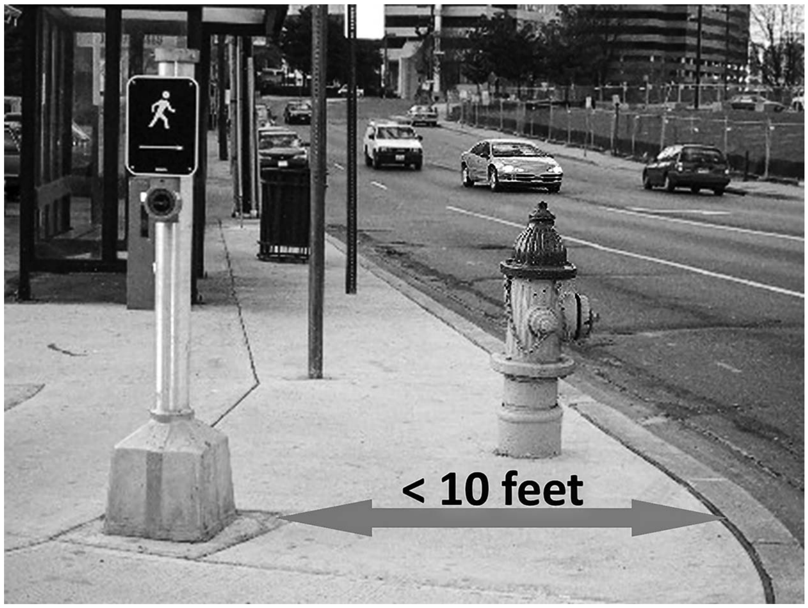

Figure 3. Push-Button Location

parallel traffic may think they are not ready to cross and may turn in front of them. If their trajectory is not correct, they may veer outside of the crosswalk and into the parallel traffic or into the idling perpendicular cars during the crossing. The pedestrian must, therefore, forgo realignment and make any adjustments dynamically while in the process of crossing the street. One way to eliminate this complication would be to provide pedestrians with a means to initiate the call button remotely without physically having to locate the pole and leave their initial location at the crosswalk.

Part One of the Study

To assist in providing travelers with information about the characteristics of an intersection, this study has explored the feasibility and effectiveness of providing some of the necessary information about the intersection through a Bluetooth beacon system that transmits voice communication over a smartphone to the user. However, any such system can be too cumbersome if it provides unnecessary information or an abundance of information that might overwhelm the traveler and complicate the crossing.

The goal of this study was to identify and provide only critical information in clear, concise language to the traveler’s smartphone. The individual would pick up the signal from the beacons during their approach to the corner and use the smartphone to listen to the information presented aurally. As part of this study, it was necessary to determine if the information presented was of high importance to the traveler, if it was presented in an appropriate order, and if the user found the information to be of value.

Table 1. Professional questionnaire results with top 11 ranked items.

Question	Min	Max	Mean	Std Dev.	N
Names of intersecting streets at corner	2	4	3.72	0.57	50
Number of lanes to cross	2	4	3.66	0.56	47
Presence of accessible pedestrian signal	2	4	3.63	0.56	48
Presence of a channelized turn lane	2	4	3.61	0.53	46
Type of traffic control signal	1	4	3.59	0.7	49
Presence of a turn lane signal	2	4	3.58	0.6	50
Presence of a work zone	2	4	3.57	0.61	49
When a corner across the street is not in alignment with the current corner	1	4	3.56	0.73	48
Directions for negotiating the work zone	2	4	3.53	0.67	49
Location of accessible pedestrian signal	2	4	3.52	0.68	46
Presence of a Median	2	4	3.5	0.62	46

The authors of this study assembled a list of 39 possible intersection information entries that could be presented to travelers with visual impairments who are preparing to cross a signalized intersection. In order to identify the information from this listing that is most critical for a crossing, a national internet survey of orientation and mobility specialists was conducted. A Qualtrics survey was made available through the Orientation and Mobility Listserv and asked the respondents to evaluate each item according to importance using a four-point Likert scale that included the following possible entries: not important at all, not very important, important, and very important. Fifty orientation and mobility specialists responded, and as a result, a list of 11 items emerged as being the most important. The means of the items ranged from 1.87 to 3.72, and the standard deviations ranged from 0.99 to 0.53. This list was presented to North Carolina traffic engineers at a North Carolina Department of Transportation–sponsored conference and gained their agreement on the importance of these items. In addition, the traffic engineers suggested expanding the item on identification of work zones to include how to navigate through or around the zone (Table 1). From this list, some items were combined, and the resulting list of characteristics included eight items.

Methods for Part One

Subjects for this study included 31 individuals who self-identified as experienced cane travelers. The authors went to an AbilityOne agency in Greensboro, North

Carolina, and to the state rehabilitation center in Raleigh, North Carolina, to seek volunteers. Individuals were asked to provide up to 3 hours of time to participate in the study and were promised a gift card in return. As a result, 35 participants were identified and 31 participated in the study with 19 coming from the AbilityOne agency and 12 from the state rehabilitation center. The subjects' ages ranged from 20 to 60 years and included both blind and low-vision users. These subjects also later participated in part two of the study.

With smartphones being ubiquitous in the general population, it was decided to develop a system of Bluetooth beacons that would deliver voice messages to travelers through their smartphones. Bluetooth beacons are electronic devices that use Bluetooth low energy to transmit information to receivers such as smartphones. They typically have a range of up to 100 or more meters. For the purposes of this study, the beacons were tuned to only register at a range equal to half the distance of the crossing so that only the beacon at the approach corner would be detected.

The researchers deployed one beacon on each of the four corners at one complex intersection in Greensboro and one in Raleigh. Both intersections had multiple lanes, dedicated left-turn lanes, APS or non-APS pedestrian call buttons, a median strip, and complex signal phasing. Each of the beacons transmitted information about the characteristics of the upcoming perpendicular intersection crossing. The beacons were programed to be activated by the users through their smartphones. For this study, four iPhones were modified for this purpose by installing the Aware app by Sensible Innovations to interface with the beacons. The app allowed robust use of the screen-reading feature in VoiceOver to read and review messages line by line.

Prior to engaging in the data collection, the subjects were trained on the terms that would be used by the beacons to describe the intersection. In addition, those travelers who were not familiar with VoiceOver gestures on Apple iPhones were taught how to use the gestures that prompt the messages.

Each subject had the option of listening to the information all at one time or controlling the phone to individually present each message. It was also possible for the subject to repeat any of the messages if necessary. Each subject was positioned approximately 100 feet from the corner of the intersection and asked to use their cane to travel independently to the approach corner. Once at the corner, they were told to activate the beacons and listen to the messages presented through their smartphone. The messages and their order of presentation included the following:

1. Name of parallel street and name of the upcoming perpendicular street
2. The direction the person is facing
3. The presence of a left-turn lane and signal arrow

4. The number of lanes to cross
5. The presence of a median
6. The alignment of the far corner with the corner the person is on
7. The presence and location of an APS push-button at the corner
8. The presence of a construction barrier and means to go around it

Four crossings were made at one of the two intersections in a counterclockwise manner. In order to ensure safety when crossing the street, the subject held onto the arm of the researcher using the human guide technique. After listening to the messages, the subject was asked to determine when it was time to make a street crossing. When the subject deemed the time appropriate to cross, the subject would tell the guide to start the crossing and would cross holding onto the guide's arm. After completing the crossing, the subject would then turn 90 degrees and walk to the approach corner at the same intersection to cross again. The procedure would then be repeated at this next leg of the crossing. This would be repeated two more times until all four corners were crossed at the same intersection. Because the width of the street, the number of lanes, traffic-light phasing, and other information differed for each leg of the crossings, specific information was presented by the beacons for each crossing. Upon completion of all four crossings, each subject was then interviewed individually and asked to evaluate the relative importance of each of the messages that they received using the same four-point Likert scale that was used in the internet survey of orientation and mobility specialists.

At the conclusion of this exercise, the researchers also asked the subjects two additional questions: "Are you satisfied with the order of presentation of information?" and "Is there other information that you would like presented by the beacons?" The subjects were encouraged to provide detailed answers to these open-ended questions.

Results from Part One

The eight items that were addressed all scored similarly high in value for participants. It is of importance to note, however, that the responses of the subjects to the importance of the items differed to varying degrees with the importance that was assigned to the items by the orientation and mobility experts. Three mean differences suggest a higher priority of the items by participants than was expressed by the experts. These differences included the presence of a median (mean 4.0, diff. +0.5, SD 0.00), location of APS (mean 3.87, diff. +0.35, SD 0.34), and number of lanes to cross (mean 3.97, diff. +0.31, SD 0.18). The overall standard deviation was much smaller among subjects than among the orientation and mobility experts,

Table 2. Top-ranked items with comparison of survey to trial.

Question	Survey Mean	Trial Mean	Diff.	Survey SD	Trial SD
Names of intersecting streets at corner	3.72	3.9	0.18	0.57	0.30
Number of lanes to cross	3.66	3.97	0.31	0.56	0.18
Presence of accessible pedestrian signal	3.63	3.87	0.24	0.56	0.34
Presence of a channelized turn lane	3.61	3.84	0.23	0.53	0.37
Presence of a turn lane signal	3.58	3.84	0.26	0.6	0.37
Presence of a work zone	3.57	3.81	0.24	0.61	0.47
When a corner across the street is not in alignment with the current corner	3.56	3.81	0.25	0.73	0.40
Directions for negotiating the work zone	3.53	3.81	0.28	0.67	0.47
Location of accessible pedestrian signal	3.52	3.87	0.35	0.68	0.34
Presence of a Median	3.5	4.00	0.50	0.62	0.00

and these three items were rated higher by the subjects than the experts. These differences may in part be due to the larger number of items evaluated by the experts in comparison to those presented to the subjects. Table 2 compares the survey means from the experts with the trial means of the subjects.

An analysis of subject responses to the two open-ended questions provided additional information on the importance of elements within the experience. Subjects overwhelmingly felt that the beacons should be detected and initiated automatically by the phones rather than requiring the pedestrian to initiate the transmittal. In addition, the majority of subjects felt that the messages should be broken down into yet smaller units that could be quickly repeated when necessary. With eight messages and some containing multiple parts, it was hard for the subjects to retain the information without breaking the messages down into segments that could be easily repeated.

Part Two of the Study

Part two of the study explored the use of a smartphone to initiate the walk cycle at an APS and, thus, avoid the need to find and press the pedestrian button. This required wireless communication between the smartphone and the traffic controller device at the intersection. This research was accelerated by the development and initial deployment of a system made by one of the engineering venders. At the time of this study, the Polara company had developed a smartphone app and a system that could communicate with the traffic control box to initiate the walk cycle. The

Peda® by Polara was designed to be installed on a smartphone so that the traveler could use the App to request the walk phase of the traffic cycle. For individuals who are blind or visually impaired, the system works with the VoiceOver (Apple) or Talk-Back (Android) text-to-speech systems to provide verbal information through their phones. This system was installed and implemented at three intersections in three key cities in North Carolina: Greensboro, Raleigh, and Charlotte. The intersections in Greensboro and Raleigh were used in this study to evaluate the system.

Upon approaching the intersection, the subject would use a gesture on the phone to signal the traffic control box to initiate an extended walk phase. Once the phase was initiated, the phone would provide a message indicating that the walk sign was on. In addition, the system would provide a countdown timer that would provide the traveler with the number of seconds remaining until the walk phase was completed.

This system allowed the researchers to evaluate the effectiveness of the system and the satisfaction with both the PedApp and the countdown information. It is of importance to note that there is a question about the benefit of the countdown timer versus its potential auditory interference. It is unknown if the addition of a verbal countdown would interfere with pedestrians' ability to use their hearing to concentrate on the movement of the traffic during the crossing.

Methods for Part Two

The installations in Greensboro and Raleigh allowed the authors to gather data on the use of the system with 31 subjects. Subjects were given an iPhone and familiarized with the use of the PedApp. Each subject would start approximately 100 feet from the corner and would walk independently to the approach corner using a cane. Subjects would use their smartphone to initiate the walk phase and then take the arm of the researcher as a guide. Once the smartphone presented the message that the walk sign was on for the crossing, the traveler and guide would cross the street listening to both the traffic and the countdown timer. After making the crossing, three similar crossings at the same intersection were completed in a clockwise or counterclockwise fashion using the same procedure.

At the conclusion of the crossings, the subjects were interviewed and asked the following six questions:

1. How difficult was it to activate the pedestrian phase of the cycle through your phone?
2. Do you like using VoiceOver gestures on your phone to call the pedestrian phase of the light cycle?

3. Would you prefer to have the app detect you automatically and call the pedestrian phase?
4. Does listening to the timing countdown interfere with your ability to pay attention to traffic?
5. Is the countdown timing helpful to you?
6. Were you satisfied with the ease of use of the app?

Subjects used a three-point Likert scale to indicate separately their satisfaction with the PedApp and countdown timer by selecting not at all, somewhat, or very much.

Results from Part Two

Twenty-seven of the 31 subjects indicated that activating the crossing request with their phone was not at all difficult. Twenty-three subjects indicated that they "very much" liked using VoiceOver gestures to call the pedestrian phase of the light cycle with two saying they "somewhat" liked using it. However, because the app was a prototype, some subjects encountered problems with reliability. There were times when the app did not function as expected.

With respect to the countdown timer, all 31 subjects reported that the timer was "very much" helpful to them. Twenty-nine reported that the transmission did not interfere with their ability to pay attention to the traffic, while two found that it did interfere. While most subjects found that the countdown timer did not interfere with their ability to concentrate on the traffic, it should be noted that the subjects were not crossing independently. Instead, they were crossing with a human guide, and thus, concentration on the traffic was not as important. Furthermore, at times, the countdown timer on the app malfunctioned and was not present, while at times, it worked perfectly. Table 3 provides a summary of the responses of the subjects to these six questions.

Conclusion

The results of these experiments indicate the value of using smartphones to present information about the characteristics of a complex intersection and to remotely call the walk phase of the traffic signal. The work presented here established both the critical information necessary to address shortcomings in intersection information (Barlow et al., 2010a; Williams et al., 2005) and a support technology to assist in calling a crossing signal (Barlow et al., 2010b; Fazzi & Barlow, 2017). Neither of these technologies was a practical solution until the societal adoption of smartphones and the expansion of Bluetooth beacon technology. The study presented here clarified the information and priority of information that was

Table 3. Results of the reaction of subjects' use of the PedApp.

Questions	Not at All	Somewhat	Very Much
How difficult was it to activate the pedestrian phase of the cycle through your phone?	27	4	0
Do you like using Voice Over gestures on your phone to call the pedestrian phase of the light cycle?	6	2	23
Would you prefer to have the app detect you automatically and call the pedestrian phase?	14	3	14
Does listening to the timing countdown interfere with your ability to pay attention to traffic?	29	0	2
Is the countdown timing helpful to you?	0	0	31
Were you satisfied with the ease of use of the app?	2	5	24

found useful by both professionals and pedestrians. It also evaluated pedestrian response to a market solution with limited testing information. There remains a specific context to these findings, and a review of the potential implementation necessary to apply them.

The intersection information requires additional review and replication in preparation for a larger trialed implementation. The current study relied on the pedestrian to rate the information but did not venture to limit the amount of information. There remains the possibility that the information shared was more than what may be necessary for efficient and safe travel. The time necessary to receive this information was less than a single traffic cycle, even with potential review, creating a significant solution to the historical dilemma of gathering intersection information (Williams et al., 2005). The solution also shared information that would not be easily discernable (i.e., work zone cautions, intersection geometry, presence of a median) through auditory means or challenging to confirm with certain visual impairments (Barlow et al., 2010a). The additional information serves as a form of confirmation prior to crossing and when encountered during a crossing. Redundancy of information and established expectations are exactly the benefit conveyed by vision and attempted with previous tactile solutions (Barlow et al., 2010a). Careful consideration is still necessary to evaluate the number of messages presented and how they are controlled. A benefit of smartphone-based information is the customization of the user interface. Toggling off information less useful to the user would allow even shorter messages without sacrificing availability to all users. There is a belief that shorter messages may be more accessible and easily repeated. A long-term benefit of an app-based solution is that feature use can be anonymously tracked and logged to provide future validity to research and development. There is also future artificial intelligence–assistant learning that would allow this information to be automatically controlled based on the number of visits to an intersection or previous skipping of information.

One limitation was the use of the built-in speaker. Because the crossings with beacons took place at complex and heavily trafficked intersections, some of the subjects had to strain to hear the messages over the sounds of the passing cars. It is already a common recommendation that travelers with visual impairments make use of bone conduction headphones when using a smartphone for directions or entertainment. These headphones allow audible messaging without blocking out or masking traffic sounds when making a crossing decision or matching the audible information with the traffic patterns present. The value of this technology paired with app-based information was reinforced during the experimental trials although it was not an explicit goal or recommended by subjects.

Two items stood out because APS installations are required to emit a tone once per second and be loud enough to be heard within 6 to 12 feet of the pole. The researchers were curious if providing verbal information regarding pole location would be redundant. The subjects, however, appreciated having information that identified the location of the upcoming pole that was across the perpendicular street. Furthermore, some corners did not have an APS, but did have a silent call button, and in those instances, the subjects found the information on the pole location to be extremely helpful.

With regard to PedApp, the subjects liked having control of the call button without having to change their line of travel. They also felt that having the countdown timers on the phone helped them determine the amount of time that they had remaining to finish their crossing. All but two indicated that the information from those announcements did not interfere with their ability to listen to the traffic. Because the crossings were made using human guides rather than independently, future studies should examine any possible interference from the timing announcements when the pedestrian is crossing independently.

The final benefit of the study was not directly related to the data collected or the specific content, but rather the methods. The process of screening orientation and mobility professionals and then confirming their assessments with travelers who have visual impairments was very successful. The confirmation provided a two-group validity to the early assumptions and the later findings. Given that many skills practiced by people with visual impairments are individualized and require customization, this approach shows promise for refining a knowledge base in a short period of time for investigation. The categorical ratings can be compared, and the descriptive statistics are not void of value in evaluating the strength of the items to each other. The forced priority of a list also provides an opportunity to explore the absolute versus relative value of items in future investigations.

In summary, this study established a starting point for the use of auditory information as an accessibility accommodation to intersection orientation. Replication is recommended, and a gradual inclusion of independent travel/crossings should be considered.

Application to Practice

Subjects said they would like to see beacons and remote call button capability available at all difficult intersections along their routes of travel. The researchers support this conclusion and recommend further research into such installations. The authors recommend that orientation and mobility specialists contact traffic engineers to determine if such installations could be established at difficult crossings. Engagement of people with visual impairments and their consumer organizations in pursuing these accommodations would also further this effort.

Further study should take place on the types of messages to display through a beacon system. With the growing number of bicycle lanes in metropolitan areas, information on their location could be helpful. Also, a description of the location and number of curb ramps at a corner might prove to be useful.

The beacons used in this study were battery powered, and often beacon installations with batteries lose power and become inoperable after a period. More permanent installation of beacons should have a wired power source to avoid this complication.

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