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Performance Comparison of Three Types of Devices Deployed in a Typical Passenger Tracking System

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Abstract
Even though the location information of travelling passengers is very valuable, offered passenger tracking solutions are not at a satisfactory cost/performance level. A cost effective passenger presence information provider system proposal is made, in present work. The design makes use of our present day's off the shelf, popular, wireless Internet of Things devices like Radio Frequency Identification (RFID) tags, iBeacons™ and Bluetooth Low Energy (BLE) adapters. Our work goes beyond a design proposal by comparing the three passenger marker devices. Single and multiple device configurations are tested and the findings are presented. Using the findings in universally accepted performance evaluators, the performance of each configuration is determined. The performance results are compared and an evaluation of the results is provided for the reader.
Keywords: BLE, Cloud Computing, Mobile Phone, Internet of Things, Passenger Tracking System, RFID

1. Introduction and Related Work

Every day millions of working people and students (passengers) are transported from their homes to their work or schools, in the world. In metropolitan areas, there is no early news from the passengers who are between their homes and destinations, due to dense population and number of vehicles. But in fact, it is possible to obtain instant information about passenger arrivals, or their location on the way. The presently introduced subject is studied under the scientific field of Real Time Location Systems (RTLS). RTLS studies have begun with research into the methods of determining object location, by using wireless devices (Want et al. 1992, Bahl and Padmanabhan 2000, Ni et al. 2004). Improvements in location detection of stationary objects, turned the research attention to location detection of moving objects (Ropponen et al. 2009, Ting et al. 2011). Next, collecting instant moving object location data matured into vehicle route tracking research (Brown and Sturza 1993, Abbott and Powell 1999, Muruganandham 2010, Shinde et al. 2015). The research resulted in one of the most important worldwide projects known as Global Positioning Systems (GPS). GPS is a hardware based navigation and tracking method applied to various commercially available consumer products (Internet 1, 2, 3). Over time, GPS has become a de facto feature in portable (mobile) phones and it is used in many areas, for different purposes. Although GPS is effective in locating outdoor objects, it is not effective in closed / covered places. Therefore, different wireless technologies are suggested in indoor location detection (Inoue et al. 2009). In a precedent study, tracking an ambulance with its crew and the assets inside has been proposed (Utku vd. 2016). Recently, portable computerized devices such as tablets, mobile phones, hand held terminals, intelligent wrist watches, miniature wearable sensors named as Internet of Things (IoT) and fast access Cloud Computing Servers (Cloud) have become available, in a complete technology package. Such availability has formed the basis of ubiquitous system proposals, providing services independent of time or location (Hiremath et al. 2015). One example is the study where the GPS coordinates of a school bus is monitored and its speed is reported to the parents (Zambada et al. 2015).

The aim of our study is to offer instant tracking of passengers transported by private or public vehicles, without dependency on a single technology, single communication method or single type of device. Three types of devices are used in the passenger tracking process. A comparison of different tracking configurations is also presented.

2. Materials and Methods.

The material shown in Figure 1 has been used in our passenger location detection work. The numbered equipment in the figure are:

1. Ultra High Frequency (UHF) battery less (passive), electronic labels (tags) working under Radio Frequency Identification (RFID) technology (1, 4),
2. Battery powered (active) iBeacon™ markers working under Bluetooth Low Energy (BLE) technology (2, 3),
3. Mobile phones with BLE feature acting as markers (5),
4. Mobile phone with BLE and GPS features (9),
5. Tablets with WiFi feature acting as report taker clients (8),
6. RFID reader for detecting RFID tags (6),
7. Hand held GPS device for GPS coordinate verification (7),

8. A passenger service vehicle (bus: not shown in Figure 1),
9. Server service from a cloud computing provider (not shown in Figure 1),
10. Custom made client (mobile phone) and server database software.

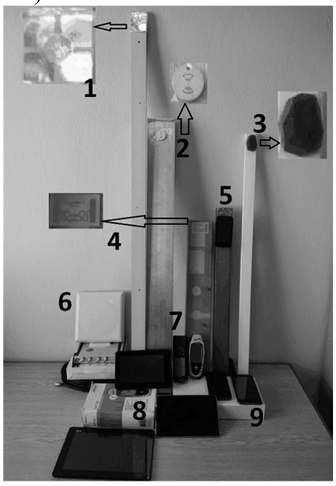

Figure 1. Devices used in the passenger tracking system experiments.

The experimentation set-up of the material used in the service bus is given in Figure 2. The RFID tags, iBeacons and the mobiles phones have been used as identification devices carried by travelling passengers. The presence of the passengers on the bus has been determined by registering the detected unique ID of the RFID tags, or the Unique User ID (UUID) of the iBeacons and/or BLE adapters of the mobile phones, onto the Cloud server. The presence of passengers is reported to the client mobile phones and tablets outside the bus, by matching recorded IDs or UUIDs to dummy passenger names created on the Cloud server. The iBeacon and mobile phone presence are detected by the mobile phone; while the RFID tags are detected by the RFID reader both placed next to the driver.

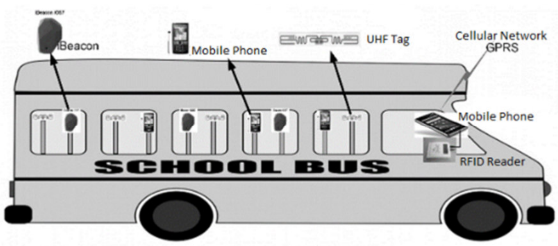

Figure 2. Deployment of three types of devices in the bus.

In the experiments, the physical presence of three types of devices RFID tags-iBeacons-Mobile Phones were tested against the reported devices on client tablets. During the experiment, tags-iBeacons-BLE enabled mobile phones mounted on posts (items 1, 2, 3, 4 in Figure 1) were used to imitate passengers sitting in the bus (Figure 3). The devices were equally positioned above and below the seat level. A GPS and BLE-enabled driver mobile phone was placed on the driver rearview mirror. Through a custom made web service application running on the driver mobile phone, the detected UUIDs were automatically sent (together with the GPS coordinates) to a Cloud database server, via a GPRS operator. In UHF tags experiments, an RFID reader (item 7 in Figure 1) was used, connected to the mobile phone via USB ports. The devices were powered by a DC adapter plugged into the cigarette lighter output of the vehicle.

Five device detection test points were assigned between the main entrance and the last bus stop, within the experimentation campus. The numbered Test Points 1-5 were chosen with an average travel distance of 3 minutes to each other (Figure 3). The presence of devices detected in the bus at the Test Points were automatically sent and saved, in the database on the Cloud server. Custom software has been developed for the detection application on the driver's mobile phone and for the result reporting application on the Cloud database server. A custom made software for client mobile phones has also been developed, in order to receive reports.

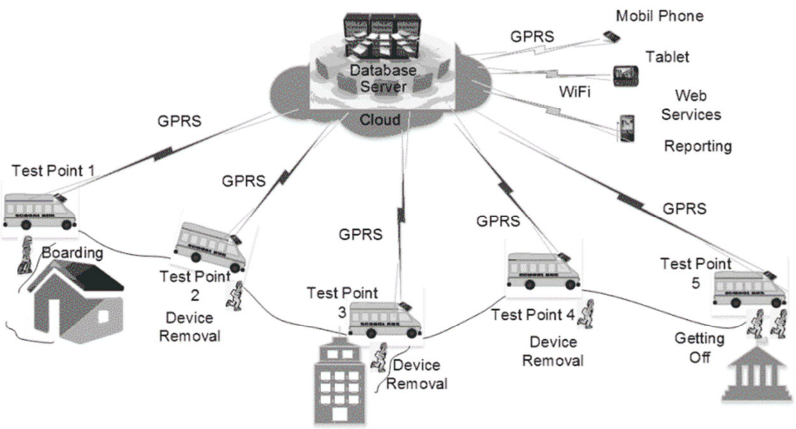

Figure 2. The overall experimentation set-up.

The mobile devices in the role of the passengers do not have any special software running. By activating the BLE property, the devices are turned into passenger markers. The experimental setup is simple and can be easily reproduced by readers. There is no need for a special supervisor to determine the device presence in the bus, because devices are recorded and placed, before each experiment run. But a person is needed to remove the devices at Test Points 2, 3 and 4. The person (lying low always at the same portion of the floor of the bus) throws the pre-determined device(s) into a scoop net, out of the window of the slow moving bus, at pre-determined test point(s).

3. Experiments, Findings and Calculated Results

Experiments were conducted in five different configurations. The setup of each experiment is described below:

1. Passenger role with UHF tags, detection by RFID reader and driver mobile phone,
2. Passenger role with iBeacons, detection by driver mobile phone,
3. Passenger role with mobile phones, detection by driver mobile phone,
4. Passenger role with UHF tags, iBeacons, mobile phones; detection by RFID reader and driver mobile phone,
5. Passenger role with iBeacons, mobile phones excluding UHF labels; detection by driver mobile phone.

3.1 Experiments and Findings

In the experiments, five pieces of each device type (UHF labels, iBeacons and mobile phones) were used as passenger markers, providing number equality. At Test Point 1 (Figure 3), 5 markers mounted on posts were attached to seats acting as passengers, with equal spacing from front to back. In the experiment where all device types were utilized, a total of 15 posts were used. In configuration 5, 10 posts were used. For each configuration, detection experiments were repeated 20 times, at each Test Point 1 to 5. The location of the vehicle was verified by the GPS device (7) shown in Figure 1, against the reported values by the driver mobile phone. At the beginning of each new experiment, the device positions in the vehicle were changed to prevent poor battery or manufacturing defect bias.

The first 3 configurations allowed collection of 500 detection findings, with 20 runs at 5 test points with 5 markers. At Test Points 2-3-4, each time a different device was removed from the bus. Thus, a total of 60 not-present detections were carried out, for each configuration. For configuration 4, 15 devices yielded a total of 1500 detection instances. During configuration 4 experiments, removing one device from each device type at Test Points 2-3-4 provided a total of 180 not-present detection findings. In configuration 5 experiments, the total number of findings was 1000; since there were a total of 10 devices in the bus. Not-present findings were 120; since each time a different iBeacon and a different mobile telephone were removed from the vehicle at Test Points 2, 3, and 4.

In the experiments, the reported presence of a device at each Test Point (verified by GPS location) was considered as a positive event. Any not-present finding for a physically present device was noted as a negative event. The number of correct or incorrect findings reported to the client mobile devices have been statistically classified as follows:

True Positive, (TP) : Number of events for correctly detecting device presence.
False Positive, (FP) : Number of events failing to detect device presence.
True Negative (TN) : Number of events for detecting device non-presence correctly.
False Negative (FN) : Number of events for detecting presence, although device not present.

The findings obtained in the experiments are given in Table 1. In configuration 1 experiments, none of the UHF tags on the back seat could be detected, at any Test Point. Also the tags before the rear seat were not detected occasionally. Hence tag detection failed in 107 cases, resulting in FP = 107. On the other hand, the least number of FP events (not being able to report a present mobile phone) took place in configuration 3 experiments (FP = 2). In configuration 4 experiments, where all device types were used, in 134 events devices were not reported in the present list (FP = 134). UHF tags were involved in most of the FP= 134 cases. In none of the experiments, any not-present device was reported as present (FN = 0). The rest of the TP, FP, TN and FN event numbers of the findings are shown in Table 1, for each experiment configuration.

3.2 Performance Criteria and Calculated Results

The recorded number of event obtained from the findings have benn used to determine the performance of the device configurations, through universally accepted equations given below (Özcanhan 2016):

$$Accuracy = \frac{\text{TP+TN}}{\text{TP+FP+FN+TN}} \times 100 \quad (1)$$

$$Sensitivity = \frac{\text{TP}}{\text{TP+FN}} \times 100 \quad (2)$$

$$Specificity = \frac{\text{TN}}{\text{TN+FP}} \times 100 \quad (3)$$

$$Error\ Rate = \frac{(\text{measured value} - \text{actual value})}{(\text{measured value} + \text{actual value})/2} \times 100 \quad (4)$$

Accuracy (Eq. 1) shows how close the reported information is to actual events on the bus. Configuration 3, mobile phones as passenger markers experiment has the highest accuracy result with 99.6%. Performance metric sensitivity (Eq. 2) reflects how many of the physically occurred (positive) events are successfully detected. In all configurations sensitivity was 100%; since no FN events were recorded. Specificity indicates how many of the non-occurring (negative) events are successfully determined (Eq. 3). Therefore, specificity performance is best for category 3 experiments (96.8%) and lowest for UHF tags (35.9%), as shown in Table 1. The error rate (symmetric mean absolute percentage error) indicates how far the reported information is away from actual events (Eq. 4). Error rates closer to 0.0% indicate more accurate reporting in the experiments. Mobile phones performance is the best.

Table 1. Test results and calculated performance values.

No	Experimental Setup	TP	FP	TN	FN	Accuracy (%)	Sensitivity (%)	Specificity (%)	Error Rate (%)
1	UHF tags.	333	107	60	0	78,6	100	35,9	21,4
2	iBeacons	429	11	60	0	97,8	100	84,5	2,2
3	Mobile telephones	438	2	60	0	99,6	100	96,8	0,4
4	All device types	1186	134	180	0	91,1	100	57,3	8,9
5	Except UHF tags	861	19	120	0	98,1	100	86,3	1,9

All performance values are tabulated in Table 1. Using the TP, FP, TN and FN values obtained for each experiment configuration, the calculated performances can now be compared. The worst performance results (Accuracy = %78.6, Specificity = % 35.9 and Error Rate = %21.4) were obtained in the UHF tag experiments. The presence determination of passengers represented by UHF tags have failed in almost one fifth of the tests. Accordingly, UHF tags have the lowest accuracy and specificity performance. With a powerful battery and a high-quality BLE circuitry, mobile phones have the highest accuracy and lowest error rate performance. With 99.6% accuracy, 96.8% specificity and only four in a thousand error rate; mobile phones are obviously the most successful devices for in-vehicle presence determination.

In configuration 4 experiments where all devices were used, interestingly the error rate was found to be higher than the sum of the individual configuration error rates. The reasons of this outcome are studied as the subject of a second research. In configuration 5 experiments, 19 FP events were recorded, while only a total of 13 FP events occurred in configuration 2 and 3 experiments. An explanation of this finding can be the interference in the 2.4 GHz BLE frequency used by iBeacons and mobile phone BLE adapters. Nevertheless, this finding is also the subject of the planned second research.

In order to estimate the price/performance ratios of the configurations, the approximate prices of the devices used in the experiments were investigated. Although the list price of each device depends on the total number purchased in a batch, presently accepted price ranges of the devices are as follows: UHF tags, 0.10-1.00 $/piece; iBeacons, 5.00-10.00 $/piece; BLE enabled mobile phones, 200.00-1000.00 $/piece. It is obvious that mobile phones are the most expensive devices, by a large margin. But, mobile phones are general purpose consumer devices and almost every consumer has one. Therefore, only the passengers with no mobile phones need to be marked by iBeacons or UHF tags.

4. Discussion

As it can be seen from the results above, mobile phones are the most successful devices in passenger tracking, in a vehicle. The RFID tags have the lowest accuracy and highest error rates. iBeacons have a reasonable error rate of 2.2%. However, when the high prices of mobile phones or their use by children are taken into consideration, iBeacons can be accepted to provide reasonable passenger tracking. Normally an iBeacon fixed to a wall is used to trigger a pre-determined application on mobile phones, within range. However, in our design iBeacons are employed as active, moving identity markers. For RFID tags, although their presence inside a bus cannot be traced all the time, the presence of a passenger can be detected when getting on or off, by an RFID reader placed near the driver. Approval of the presence and number of passengers is the responsibility of the vehicle driver; via an "OK" button on the driver's mobile phone screen. Abnormal situations can be easily checked through the provided pre-determined passenger list. The inspection and approval procedures can be made by an authorized assistant, as well.

An inherent contribution of our work is the detection of an improper passenger in a vehicle; in other words, passenger in the wrong vehicle. Another inherent contribution is the detection of an additional foreign passenger in the vehicle. Foreign passenger is detected when the number of passengers counted by the driver does not match the number of the list, provided on the driver's phone. A limitation of our design is the difficulty in the detection of foreign passengers, when equal number of regular passengers are absent. In such a case, a roll has to be taken.

Taking the prices into consideration, one of the most important contributions of our work is the use of free or low-cost technologies like BLE, GPS, WiFi, RFID. Our proposed system provides the same price-performance tracking service, compared to more expensive commercial solutions. Most commercial solutions are single technology, based on mobile phone operators that require monthly high maintenance and subscription fees. In our method however, only the driver phone uses the GPRS service; the rest of the devices only need BLE or WiFi feature. However, our system provides a choice for paid and free wireless technologies, depending on the performance expected. The globally accessible Cloud Computing used has a small subscription fee, but can be replaced with a database running on a small size propriety server.

5. Conclusion

A passenger tracking system utilizing off the shelf, widespread and inexpensive technologies has been presented. The proposed system allows passengers to be traced, at affordable costs. Three devices and five configurations have been presented to the reader. The configurations have been compared to give the readers a chance to choose between devices and different combinations. An estimation can also be made on the price/performance ratio of the presented configurations. Instead of commercial solutions with high annual costs, the users are encouraged to develop their own solutions, or take our proposal as a reference point.

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