Participatory-sensing-enabled Efficient Parking Management in Modern Cities

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Abstract—**A growing interest in Internet of things (IoT) paradigm has enabled a wide range of physical objects and environments to be monitored in fine detail by using pervasive sensing and communication devices. In this paper, we develop an IoT framework that targets one of the biggest challenges in modern cities, namely, Parking Management. Populating parking facilities with sensors imposes unwarranted installation and maintenance costs. In our system we eliminate the additional sensing or monitoring facilities, instead use participatory sensing paradigm to find, monitor and regulate parking. In our system volunteers collect and share information from their local environment using smart-devices. We link the user reputation scores to the reliability of user-provided data and determine parking availability and combine them with a reward model for incentives. The validation results through simulated as well as real participatory users have shown that our approach can yield accurate parking spot availability using user provided data.**

Keywords: **Internet of things, mobile applications, Participatory sensing, parking management.**

I. INTRODUCTION

The Internet of things (IoT) is a novel paradigm that has been recently gaining popularity in the technical community [1]. The basic idea behind it is that objects around us have a pervasive presence of Radio-frequency Identification (RFID) tags, sensors, actuators, mobile phones, etc., which are able to interact with each other and cooperate with their neighbors to achieve common goals. With the advancements in mobile phone technology over the past decade a new generation of smartphones have emerged that are equipped with various types of sensors and high processing abilities. Now, people are increasingly able to create, collect and distribute data via the Internet. These new trends that have given rise to social media, pervasive connectivity, and consolidated data centers, has led to the new sensing paradigm that is popularly known nowadays as 'Participatory Sensing' [2], and have created a public that can objectively record, analyze and discover a variety of patterns that are important in their lives. Using portable devices with sensors like cameras, accelerometers, GPS, etc., a new collective capacity has emerged, where people participate in analyzing various aspects, that were previously invisible or unknown. These smart devices are quickly growing in sophistication, e.g., eye-wear and wrist watches [3], and popularity, are gradually becoming essential for everyday use.

In a participatory sensing system, the community of participants owns the entire process and is vested in its outcome of research and discovery. By combining the local knowledge and individual empowerment with widespread technology, this approach develops a community's potential for self-determination. A key challenge with such network based information distribution is that people are less motivated to forward information when the cost or effort is significant. A simple solution for that is to provide incentive for what they provide. However the success of such an application requires a high participation from voluntary users. Unfortunately, the very openness that allows anyone to contribute data also exposes the applications to erroneous and malicious contributions. This makes it imperative that the applications server evaluates the trustworthiness of contributing devices so that corrupted/malicious data is identified. Such reputation mechanism [4] can be used to get reliable outcomes.

In this paper, we apply the Internet of things and participatory sensing paradigms to target one of the biggest challenges modern cities are currently facing, namely, efficient management of vehicle parking spaces. The limited availability of parking spots results in traffic congestion, air pollution, wasted time and productivity, as well as driver frustration. The cost for parking expansion is often prohibitive, especially in cities. The main challenge in efficient parking management is to locate and optimize the use of available parking spots. Over the past several years researchers have developed several methods to keep track of spot availability using sensors, cameras etc. [5,6,7]. However, such an approach imposes additional cost for installing and maintaining hardware devices. We propose a novel solution based on the use of portable personal device. The idea is to involve voluntary users to provide parking availability information.

Smart portable devices have proliferated our lives so much that it is safe to assume everyone using a vehicle parking system is bound to have at least one such a device while being on the road, hence eliminating the need for any additional hardware for managing the parking space. We propose a system that leverages these devices to accurately determine parking availability. A user is incentivized to provide useful information such as parking spot availability. Our approach employs a reputation system to aid in acquiring trustworthy data and uses a simple rewarding mechanism to reward users reporting correct information. A score is associated with each contributing device to reflect the level of trust perceived about the spot availability reported by this device over time. More active participation from volunteers gives better accuracy in determining parking availability. Our results show that even with moderate user participation it is possible to determine parking availability with reasonable accuracy without the need of additional hardware or extra cost.

The rest of the paper is organized as follows. The next section discusses the related work. We describe our framework in detail in Section III. Section IV gives a brief overview of our current prototype implementation, discusses the simulation experiments and highlights the results. Section V concludes the paper point out our future work plan.

II. Related Work

There are numerous applications that provide parking information to users. From popular services like Google Maps and Bing Maps to other parking dedicated applications such as Parkopedia and Primo Spot. All these systems report on parking rates and provide interface through tablets and mobile phone applications. They mainly focus on navigating the user to find a nearest or cheapest parking lot, and do not have information about spot availability.

Several models of parking management have been developed over the years. Most of these systems opt to minimize congestion due to vehicle slow down, and maximize the utilization of parking resources. The majority of these parking management systems employs either vision-based, RFID-based or wireless sensor networks (WSNs) based methods to track space availability. RFID-based systems such as [10] attach RFID tags to vehicles and place readers at the parking lots to detect and keep track of spot usage. When a WSN is employed, sensors at each parking spot or at regular intervals are used to check the availability. A number of sensing modality, e.g., motion, weight, light etc. has been considered to detect the presence of a vehicle in the parking spot. This data is aggregated and used for parking management. Several other systems [11] use video surveillance cameras and different video-based vehicle detection techniques to get parking information.

However, there is a common disadvantage in these parking systems is that, all incur levy expenses in various forms in order to run and maintain them. RFID tags, sensors and video cameras all impose financial burden to install and maintain the hardware. In many cases the cost to benefit ratio of such hardware is so high that it becomes difficult to maintain them, as it happened in the case of San Francisco Transit Authority, where the use of sensor-based parking was abandoned due to high maintenance expenses [12]. There are a few other IoT based Parking management models such as [13] that use sensor networks and IoT to collect and disseminate parking data easily. Albeit, using sensor networks incur installation and maintenance costs.

The emergence of participatory sensing has resulted in the development of several people-centric and environment-centric sensing application models such as [14] that use mobile devices for crowd sensing. But with Participatory sensing and IoT, it is easy to provide false data. Which has led to the development of several mechanisms to ensure that the data collected is trustworthy and authentic. In [4] the trustworthiness of a device is determined by assigning a reputation score that gets elevated every time a device sends non-corrupt data.

III. Participatory Sensing Based Parking Assistance

Parking is not just how much time it takes to secure a slot, but to deal with the whole parking process. We view our proposed system as a part of a bigger framework for Parking Management, which will have a lot more sensing variables and functionality, like GPS location, camera, etc., to improve user-experience, and operation efficiency. The complete mobile framework will display real-time information about the parking availability. This paper focuses only on the participatory sensing component of our smartphone application. The app depends on data reported by individual users, and a generalization framework that calculates the availability based on our algorithm.

A. The Framework

The proposed framework consists of three main players with interaction and operation flow as illustrated in Figure 1.

- Users act as requestors, looking for available parking and declare it used, when they park, and unused, when they leave. Users can also act as reporters, informing the system about the occupancy of parking spots, when they are in the vicinity of the parking lot. This process can be further improved by modern smart gadgets and using a combination of sensors such as Camera, GPS and accelerometer, to detect and report availability. This can also be automated by using wearables such as Smart eye wear, smart-watches, etc.
- Parking Spot: A parking spot is a static entity with no active role of its own, but is the main entity joining the Requestor and Reporter with the reward and reputation models. A parking spot has its availability status-whether it is in unknown, used or empty, and its reporting status. The current status that is being computed by the server using our framework of participatory sensing. A parking spot can only toggle between 'Unknown', 'Used' and 'Unused'.
- Server: The server is the middleman between the User and the Parking spot. It maintains processes and communicates the information about the availability and reporting status of the parking spots. It is also responsible for calculating the user reputation and rewards. The user requests information from or reports data to the server. Using the data received from users, the server assesses the parking availability using the reputation model. The server can be hosted by the organization that own or manage the parking area. In our prototype implementation, we use Google Cloud Platform and services to host the app, store the data as well as perform the necessary computations.

B. The Architecture

Our system consists of a reputation mechanism that minimizes malicious reporting and gives accurate spot availability. We further minimize inaccurate reporting by allowing spot status reporting only when the user is in the vicinity of the spot, by using GPS sensors on the device. Every 'User' has a Reputation-score from 0 to 99, where 99 reflects a user with the best reputation. It is the measure of estimated truthfulness of the Reporter. Every time their sensing is found to be false, their reputation-score gets decremented and vice-versa. A user can never have a 100 reputation, implying that a user cannot single handedly change the spot status without being confirmed by at least 1 other person. The truthfulness of a user's report of a spot availability is based on the status reported and hence verified by other user(s) for the same parking spot. Every correct reporting, increases the reputation score, and decreases on an incorrect report. Each parking spot has a pre-defined timeout, after which even if the spot status has not been finalized, benefit of doubt is given in favor of the user and they get partial credit in their reputation. The Spot Reporting Timeout is computed based on learning, and is a factor of frequency of users reporting.

Reputation scores of individual users are reset every predefined number of days. All users' reputation scores do not reset on the same day, but on random days instead. A user can also report that they themselves have used a parking spot, and then report again on departure. Failure to report on departure leads to decrease in reputation score.

Availability Computation: The parking spot availability is computed based on the reporting by multiple users, based on the following formula.

$$SA_x = \sum_{U_{used}} Rep_{Score} - \sum_{U_{unused}} Rep_{Score}$$

Where, SA_x reflects availability of parking spot 'x', U_{used} and U_{unused} indicate a user reporting 'Used' and 'Unused', respectively, and Rep_{Score} is the user reputation score.

If SA_x <= -100, then spot is confirmed 'Unused', and if SA_x >=100, then the spot is confirmed 'Used', and unless it goes beyond either of these values, its status remains as is. If reputation scores of users are low then it would take more users to verify the availability of a spot, which automatically minimizes malicious user reporting. In the same way, users with high reputation scores, help in getting accurate availability quickly, since their reporting needs to be verified with lesser number of reporters.

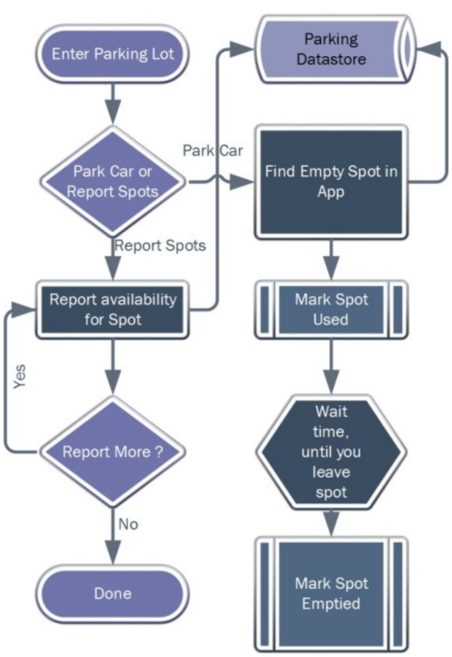

Figure 1: A flowchart description of the basic operation of our proposed participatory parking management system.

IV. Implementation and Perfromance Evaluation

A. Prototype Application

Our initial prototype application is built for Android devices. In the application users can view the parking spot availability and navigate to it. Users can also report the availability of spots if they are in close proximity. The app calculates the spot availability based on the logic explained in the previous Section III. An approved user also has the ability to define parking lots and populate a lot with spots, which also becomes a participatory way of adding new parking facility into our system. We use the Google Cloud Platform to host our app, store the data as well as run the processing and analysis. Figure 2 shows sample screen shots.

B. Experiment Setup

To assess the accuracy of the system, we simulate a number of users with smart devices that would provide participatory data. We also use some real users with real devices to provide the data. We compare the true spot availability information with the calculated spot availability by our framework. We consider a real world scenario of the parking Lot 22 at UMBC that has 480 parking spots. We use the real parking availability information of total number of cars occupying a lot at a given time of day for a range of days, as provided by the UMBC Parking Services. We run each of the simulation for Monday to Thursday. In the simulation the following assumptions are made. A person's reputation score is reset every 7 days, and the parking spot availability is reset

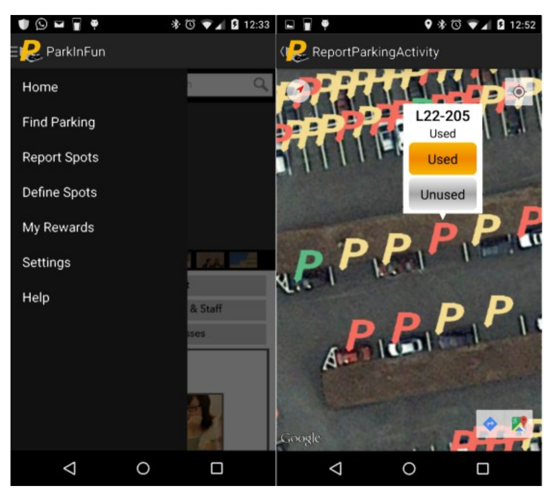

Figure 2: Screenshot of Android App

to Unknown every midnight. The average number of reporting users follows Poisson distribution with $\lambda = 60$.

Since we do not use an artificially intelligent agent to simulate human behavior in reporting the spot availability, we use a fixed 'truthfulness' level. Say, for a particular simulation we use truthfulness of 90, then a particular simulated user would report the true availability 90% of the times. A simulated user's truthfulness not only helps in varying their reputation score, but also in eliminating the element of frequent change in parking spot status. A user earns reputation points for correct report, loses points for incorrect report and gets partial reputation points, for benefit of doubt in case the spot times-out. In addition a user earns reputation points for reporting that he parked his car on the spot, and loses points on failure to report that he emptied his parking spot.

C. Simulation Results.

Figure 3 shows the results based on the average of the four days. We observe that as the day progresses our system reports accurate status for 83-90% of the spots, a majority of the remaining spots are displayed as Unknown, and very few are reported inaccurately. Since there are fewer users reporting early in the day, it is difficult to verify the availability, which results in more inaccurate reports. That drastically tapers down after 10:00 AM as the number of participants increases. We have studies the effect of the average number of participants. As indicated by the results in Figure 5, the number of users does matter, but only up to a certain extent, after which the accuracy does not considerably improve with the increase in reporting user count.

We have also varied the average reputation score range of all the reporting users. In a real scenario it is impossible for all users to have a low reputation score or all to have a high reputation score, but our results shown in Figure 4 that even with all users having scores between 40 and 55, our system would still display accurate availability for 53-58 % of the spots, while majority of the rest are displayed Unknown. Figures 6, shows the effect of varying the truthfulness range of users. The figure indicates that if users are reporting the spots honestly, it will lead to accurate spot availability; however reporting false status will only result in more Unknown values and does not increate inaccurate spot status. This does give significant insight in our system, about how user's honesty would matter, but with the reputation system and applying location constraints in reporting the spot status, we assure a high level of true participatory reporting.

V. CONCLUSIONS

We have presented a participatory sensing framework for tracking parking spot availability. We validate the accuracy of our system with real and simulated users. The results have demonstrated that it is possible to accurately determine parking spot availability using data reported by users. Higher number of participatory users gives more accurate availability. We eliminate malicious users with our reputation mechanism. Our future work will address the incorporation of a reward model to motivate user participation through incentives. We also intend to collect and use the parking usage data for analytics and further learning to improve our application accuracy. We also intend to integrate external applications such as payment gateways, RFID readers as well as local data-stores to further improve upon our system.

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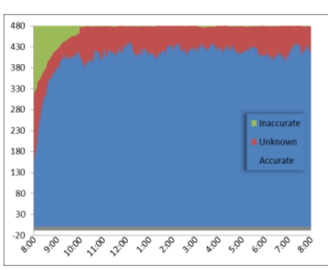

Figure 3: Average accuracy of system.

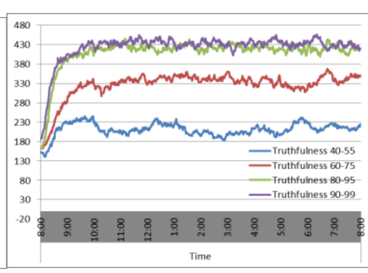

Figure 4: Number of accurate spot reports with varying truthfulness.

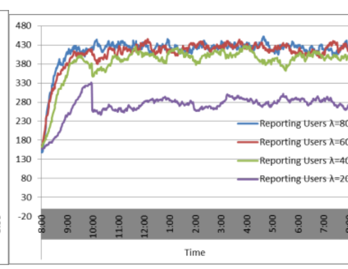

Figure 5: Number of accurate spot reports with varying reporting users.

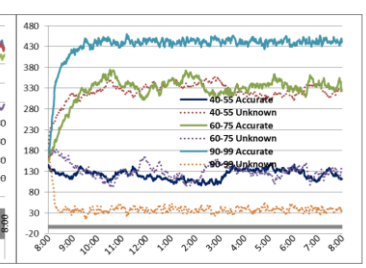

Figure 6: Number of accurate and unknown spots with varying truthfulness