An Automatic Attendance Checking System using Smartphones: An Infrastructureless Approach

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Abstract—In this paper, we design and implement an attendance checking system that can automatically check whether students with their smartphones are inside the classroom or not. We seek to figure out the geospatial relations of the students by making their smartphones transmit and receive the beacon frames of the Bluetooth Low Energy (BLE) technology. To this end, we measure how BLE signals attenuate and how obstacles affect the propagation of the BLE signals. Based on the observations, we design the attendance checking system that can estimate whether the students are inside or outside the classroom. The BLE measurements of the smartphones are combined and used to classify the students by K-means clustering. By conducting experiments in real testbeds, we demonstrate that our system can successfully check the attendance of students.

Index Terms—Indoor localization, Geo-fencing, attendance checking, BLE

I. INTRODUCTION

Over the last decade, the importance of accurate indoor localization has increased for pervasive computing centered around smartphones. The location of a user is provided by location-based services (LBSs) such as indoor navigation, marketing, and asset tracking. In indoor environments, we cannot rely on GPS signals for positioning since they cannot penetrate well through the construction materials. Thus, indoor positioning technologies rely on other sources like radio waves, magnetic fields, acoustic signals, vision and so on. In recent years, as smartphones become common among people, researchers have focused on localization based on WiFi or Bluetooth([1]).

LBSs can be used for educational purposes. Since most students carry smartphones now, we are motivated to design a system that can check the attendance of students with smartphones. In particular, we notice that almost every smartphone has a Bluetooth Low Energy (BLE) interface. The proposed attendance checking system is one of geo-fencing ([2], [3], [4]) applications. The design criteria of such systems are how accurately we can estimate whether a target is in the specific area, and how easily we can deploy the system. If we can install BLE beacons inside and outside the classroom, it is easy to check the attendance of the students ([5]). However the manual installation of BLE beacons and their power management make it not so attractive from the economical and operational points of view. Instead, we seek to design an attendance checking system that does not require any infrastructure; the students and the instructor of a class only need to bring their smartphones.

II. BLE MEASUREMENTS

The proposed system exploits the received signal strength (RSS) of a BLE signal. Android smartphones support hooks on BLE transmissions since API 4.3, which provides four power levels (1, -7, -15, and -21 dBm) and three intervals between successive beacon transmissions. In our system, students’ smartphones take turns in transmitting and receiving BLE signals and the system collects the measurement data from every smartphone and estimates whether the user is inside the classroom, outside the classroom wall, or far from the classroom. To do so, we need to identify how the RSS varies depending on the environmental factors like walls, obstacles/distance between smartphones and so on. We first conduct experiments to find out the effect of various obstacles. We use the average RSS and the number of beacons successfully received (per interval) as metrics. In addition, each smartphone measures both metrics for each power level to find out whether the power level can be a useful indicator in checking the existence of a wall between the BLE transmitter and the BLE receiver. It turns out that, in real environments, most wireless signals including BLE are influenced by various factors. In this section, we seek to assess the impact of the factors on the strength of a BLE signal.

A. Wall Obstruction

We conjecture that the wall could affect the BLE transmissions substantially ([6]). To investigate the influence of the wall, we set up an experiment as follows. Fig. 1 describes our experimental settings. In this environment, we have a 7cm thick (metal) wall along with a 29cm thick (wooden) bookshelf, which separates the inside and the outside of the classroom. We measure two cases. For the first case (Fig. 1 (a)), we place two phones inside the classroom and set its distance to 2.4m. For the comparison purposes, in the second case, we place one phone inside and the other one outside the classroom as shown in Fig. 1 (b) and set the distance between the phones to 2.4m, but this time the wall is in the middle of the two phones. If the wall affects the BLE signal propagation, the RSS would show different characteristics.

Fig. 2 is the measurement results of the experimental settings in Figure 1. We use the two metrics to check whether
the RSSs of the two cases show different characteristics. We measure the average RSS and the observed beacon count from the BLE beacons. As for the beacon count, a phone transmits beacons for 15 seconds for each power level (8 beacons per second). In Fig. 2, the blue line is the result of the first case and the red line plots that of the second case with the wall in-between. Obviously, the wall noticeably diminishes the average RSS and the difference in the RSSs of the two cases is higher than 10 dBm for every power level. For the beacon count, the receiver observes almost every beacon for every power level in the first case. However, for the second case, the beacon count is substantially reduced, especially as the power level decreases. Thus we observe that the wall clearly influences the BLE transmissions between the two phones.

**B. Effect of wall, human body, and distance**

In the previous section, we noted that the wall can be the main source of the attenuation in the BLE signal propagation. However, there are some other possible sources of the attenuation/hindrance. In this section, we carry out experiments to collectively assess the impact of the possible sources of hindrances like a wall and a human body. Obstacles located on the line-of-sight path between two phones will block the propagation of a dominant direct signal, which may significantly reduce the RSS at the receiver side. Furthermore, the other factor of wireless signal attenuation is the distance between the transmitter and the receiver. The strength of a signal exponentially decreases as the distance between the two phones increases. Therefore, we also conduct experiments to assess the signal attenuation by the distance, which is compared with the obstacle cases. To analyze how these factors affect the attenuation of a BLE signal, we set up experimental settings as shown in Fig. 3. In this environment, the wall of the classroom is 24cm thick (cement). We test the cases of wall and human body hindrances and the case of no obstacle. In the last setting, there is no obstacle between the phones but the distance between the phones is doubled (4.8m) to make its RSS pattern exhibit the similar pattern with the wall case.

**III. System Design**

In this section, we will describe the architecture of the proposed attendance checking system and its mechanisms. As discussed in the previous section, a few factors can affect the BLE attenuation, which makes it harder to determine whether a particular smartphone (of a user) stays in the classroom or not. To find out whether the smartphone is in the room or not, we need to identify how its beacon is received by the other smartphones and how it measures the RSSs of the other
smartphones. In particular, when we analyze the RSS of a beacon, we need to figure out whether the attenuation (of the beacon signal) results from a wall, from a human body, or from the distance between the two phones. Recall that it is hard to tell which factor affects the BLE signal propagation when we observe a single pair of phones. The central idea of this paper is to observe multiple pairs of phones collectively. When we consider multiple pairs of phones in the classroom, some pairs may be obstructed by human bodies and so on. However, some other pairs may have direct paths between them (so-called the line-of-sight propagation). If some students are behind the wall, they will receive substantially attenuated signals from all the students in the classroom. In this way, we believe our system can differentiate the students in the classroom and the ones outside the classroom.

Our system is comprised of two components. The collection component fetch the BLE measurement data from the phones for checking attendances. Suppose phones are located either inside or outside the classroom. A phone transmits its BLE beacons, and other phones collect the beacons from the transmitter and measure the RSSs of the beacons. Note that the receivers know the original power level of a received beacon, which is recorded in the payload of the beacon message. Each phone takes turns in transmitting and receiving beacons. After a round of BLE transmissions and receptions is finished, the collection component collects the data measured from each phone.

The analysis component analyzes the data collected by the first component. Fig. 5 illustrates how the analysis component handles the measurement data. First, there is a dataset from the collection component at the top right of Fig. 5. The dataset consists of multiple entries, each of which contains the transmitter, the receiver, the RSS value and the transmission power level. By analyzing the dataset, we can classify the phones into the ones inside the classroom (in-group), and the ones outside the classroom (out-group).

![Fig. 5: The operation of the analysis component is illustrated.](image)

We use the K-means clustering algorithm to classify the phones into two groups from the point of view of each phone. First, we classify the phones randomly into two groups and calculate the average value of each group. The value we use here for clustering is either the RSS or the beacon count for a particular transmitter and its particular power level. Then, for each phone, we check its value (RSS or count) and we classify it into the group whose average is closer (to its value). That is, a phone can change its group membership if its value is closer to that of the other group. This reshuffling iterates until the group membership does not change. The whole process will classify the phones into two groups to minimize their standard deviations (of the value of interest).

Note that a smartphone of a teacher/instructor is called a seed node. After separating the two groups, we label the group as “in-group” if the group contains the seed node, and the other group as “out-group” that does not include the seed node. We assume that the seed node is always in the classroom. Lastly, we collect the group classification result for each phone and count the number of the occurrences of the particular phone classified as out-group. The conjecture is that a phone located outside the classroom is likely to be classified more frequently as out-group.

**IV. EXPERIMENTS**

We test the proposed system with the following settings. As shown in Fig. 6, we use total eight phones, six of which are evenly distributed in the classroom while the other two are located right outside the classroom. During the measurement/collection process, only one of the phones becomes the transmitter at a time, and the others will receive its beacons. The role of the transmitter is shifted among the 8 phones in a round. Each round takes 12 seconds, and the transmitter changes its power level every 3 seconds. (There are 4 power levels.)

![Fig. 6: We place six phones inside the classroom and two phones outside the classroom for the experiment.](image)

Fig. 7 shows how the 8 phones are classified when the RSS and the beacon count are used as the metric for classification. Using the average RSS and the beacon count for each pair of phones, we classified the phones into two groups. Then we count how many times each phone is classified as out-group for each phone and for each power level. Therefore, a phone can be classified as out-group maximum 32 times. Note that 32 = 8 (the number of transmitters) * 4 (the number of power levels). Fig. 7 shows that there is a clear difference between the phones outside the classroom and the ones inside. The RSS-based classification exhibits the stark contrast between the two groups. While the beacon count-based classification shows somewhat less differences, the phones inside the classroom
are still classified as out-group less than half compared with the ones outside the classroom.

![Graph](image)

Fig. 7: The RSS-based K-means clustering algorithm shows the greater differences between the two groups than the count-based one.

V. DISCUSSIONS

In this work, we have implemented and tested the proposed automated attendance check system and our experiments showed that the system achieves good performance within a real classroom environment. However, our work still have a room for improvement. Since we have used the K-means clustering algorithm to classify students, we need to predefine the number of clusters of students before we check the attendance. In our experiments environment, we use the number of clusters as two (K=2), assuming that students are clusters as two groups, one group for students inside the classroom and the other group for students outside the classroom. However, in real situations, students may form more than two clusters. For example, consider a case that some students form a group in the classroom, other students standing outside the left wall of the classroom, and the other students standing outside the right wall. With the cluster number being two, we may not be able to correctly classify students. Also, there can be situations where some students form two (somewhat distant) groups inside the classroom if the classroom is large. In such cases, the proposed scheme may result in many false negatives.

To solve this issue, we plan to use another clustering algorithm that does not require a predefined number of clusters. In particular, we take into account the DBSCAN ([7]) algorithm that is a density-based spatial clustering algorithm. DBSCAN does not require the number of clusters, but rather takes two input parameters: the minimum number of points that can form a cluster, and the maximum distance between two samples for them to be considered as in the same neighborhood. Selecting a proper input parameters is not a simple task, but not requiring the number of clusters in advance can be advantageous for the real attendance checking scenarios. Furthermore, DBSCAN separates out noise points that does not belong to any cluster, which may help identify some students outside of the classroom who stay alone. For future work, we will implement the system based on the DBSCAN algorithm and conduct experiments considering more various and realistic classroom scenarios.

VI. CONCLUSIONS

In this paper, we developed a system that can check the attendance of students automatically using only BLE-equipped smartphones. Our objective is to substantiate the notion of geo-fencing without any infrastructure support. We comprehensively analyzed the propagation characteristics of BLE transmissions and identified the factors that affect the BLE signal attenuation. Based on the BLE signal measurements, we designed and implemented the attendance checking system that effectively classifies the phones into two groups: the ones inside the classroom (in-group) and the ones outside the classroom (out-group). We rely on the K-means clustering algorithm by which each phone compares its RSS values (or its beacon count) with the ones of the other phones. The testbed-based experiments show that the proposed system can successfully classify phones into in-group and out-group.

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