Telepubbies: A Wi-Fi Based Indoor Positioning System

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Abstract

The Global Positioning System (GPS) has been widely used for decades, but unfortunately this technology is still not useful in some conditions, such as indoor or mid-scale environment. In this paper, we investigate this research question and propose a novel solution for indoor environment. *Telepubbies*, a Wi-Fi-based indoor positioning system, geolocates the user's position based on signal strength of surround Wi-Fi routers. The system was designed, implemented and evaluated in a campus environment. The results showed that this proposed solution worth more time to investigate its impact and scalability.

Keywords – Wi-Fi Positioning System, Undergraduates, Hands-on Learning.

I. INTRODUCTION

The Global Position System (GPS) based navigation systems are the primary geolocating method. The GPS systems are useful when navigating on the road or finding a location based on its street address. However, when one needs to navigate the inside of the buildings or between crowded high-rise buildings, the accuracy of GPS significantly decreases. Furthermore, many indoor or mid-scale environments have complicated layouts that can be confusing to people not familiar with it. In order to solve these problems, most organizations offer printed static maps as well as an information center to answer questions and direct people to their desired location. However, those static methods are useless if someone is already lost.

In this paper, we investigate the issue of indoor positioning for undergraduates. Although this issue has been actively studied in the past [1-5] with different approaches [7, 8], it is hard to find a solution at the undergraduate level. Since it requires greater research and strong theoretical and mathematical knowledge, the solution can be too complicated or theoretical to the undergraduates. In addition, there are still many limitations, such as difficulty and cost in the deployment, proprietary solution, etc. Since most organization, including schools or companies, already have Wi-Fi covering the entirety of their campus or buildings and most people already have a Wi-Fi enabled device like a smartphone, we propose to use exiting Wi-Fi routers for positioning object in an indoor or mid-scale environment.

Navarro and others of Cal Poly published a paper about Wi-Fi localization using the relative received signal strength (RSSI) fingerprinting [6]. They implemented the fingerprinting method on a playground of their Child Development department. They collected signal strengths from six routers at each reference point as shown in Figure 1. With the fingerprinting method, when a user receives signals from six routers and the user's device will find the closest location based on its fingerprint database of router signals. They used the fingerprinting method over the triangulation method. Even though the triangulation method is relatively simple to implement, the fingerprinting method had promising results with various ways of making predictions [1].

In this paper, we present a simple but practical Wi-Fi localization solution for the undergraduate by utilizing RSSI fingerprinting method.

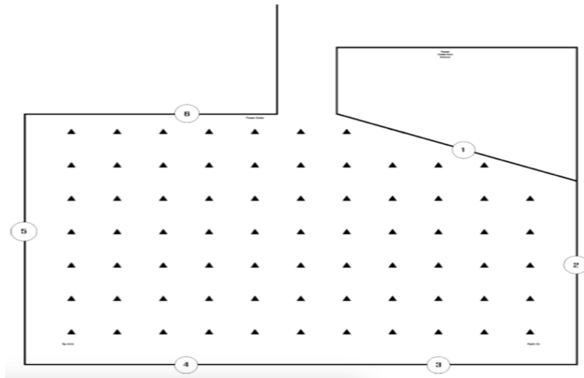


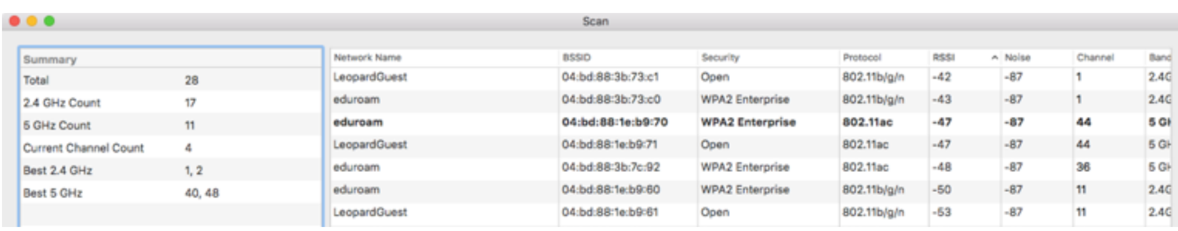
Figure 1: Router and fingerprinting reference points. Circles represent routers and triangles represent reference points.

II. *TELEPUBBIES*: A WI-FI BASED POSITIONING SYSTEM

Generally speaking, Wi-Fi routers have unique media access control (MAC) addresses, which allows devices to differentiate themselves, especially since some environment may have a number of routers in close proximity to one another. The *Telepubbies* system collects the signal strengths from theses routers to determine a user's location. In this section, we present our solution for both of macOS and Windows systems respectively.

A. macOS Testing Device Setup

For the Mac users, the built-in network interface utility, Airport, can be used. Airport has both a graphic user interface (GUI) and a command line tool. Figure 2 shows output of Airport GUI. GUI provides Network name(SSID), BSSID(MAC address), security, protocol, RSSI(signal strength in dBm), channel, and etc.



Scan

Summary	
Total	28
2.4 GHz Count	17
5 GHz Count	11
Current Channel Count	4
Best 2.4 GHz	1, 2
Best 5 GHz	40, 48

Network Name	BSSID	Security	Protocol	RSSI	Noise	Channel	Band
LeopardGuest	04:bd:88:3b:73:c1	Open	802.11b/g/n	-42	-87	1	2.4G
eduroam	04:bd:88:3b:73:c0	WPA2 Enterprise	802.11b/g/n	-43	-87	1	2.4G
eduroam	**04:bd:88:1e:b9:70**	**WPA2 Enterprise**	**802.11ac**	**-47**	**-87**	**44**	**5 GH**
LeopardGuest	04:bd:88:1e:b9:71	Open	802.11ac	-47	-87	44	5 GH
eduroam	04:bd:88:3b:7c:92	WPA2 Enterprise	802.11ac	-48	-87	36	5 GH
eduroam	04:bd:88:1e:b9:60	WPA2 Enterprise	802.11b/g/n	-50	-87	11	2.4G
LeopardGuest	04:bd:88:1e:b9:61	Open	802.11b/g/n	-53	-87	11	2.4G

Figure 2: Airport GUI Output

Airport command line tool provides everything the GUI provides as well as other minor details, such as age, AP mode, beacon interval, capabilities, information element, etc. Like other command tools, exporting data from the result is significantly easier than the GUI. This Airport command line tool also provides results in the Plist (Property List). Plist is a type of XML and can be extracted as an array and handy with existing XML libraries as shown in Figure 3 (Left).

B. Windows Testing Device Setup

For the Windows users, Netsh command can be used. The command "`netsh wlan show network mode=bssid`" will display the list of all routers that the computer is able to scan, as shown in Figure 3 (Right).

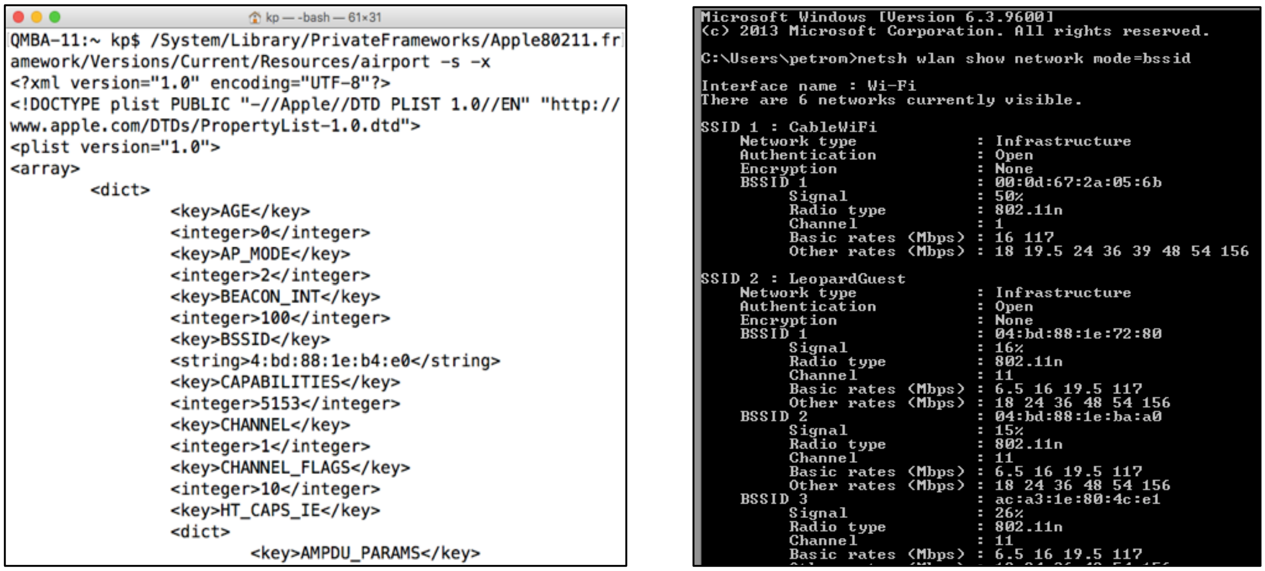


Figure 3: Output of Wi-Fi Scanning Tools. (Left) Plist XML of Airport. (Right) Netsh of Windows Command Line.

C. Collecting RSSIs

In order to provide location results, we need to construct a fingerprint database of router signals. If we can have more reference points and collected data, we can definitely improve system performance. Instead of providing a reference point (a localization result), we decided to provide the results at the room-level localization. Thus, by finding signal strength (RSSI) of the boundaries of a room, our system can show if you are in the room or not. Figure 4 shows a floor plan of the testing building and our reference points for finding boundary signal strengths.

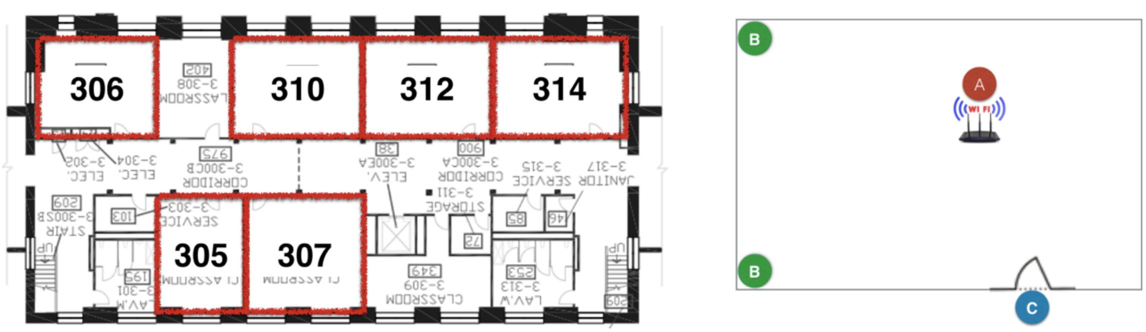


Figure 4: Floor Plan (Left) and Reference Points for each room (Right).

As Figure 4 illustrates, each room has a Wi-Fi router with two or four MAC addresses, except for room 308, which does not have a router, and room 309 which was inaccessible. Room 305, 306, 307, 310, 312, and 314 are used for this research. To provide room-level localization results, a few signal strengths from inside and outside of a room are needed first. When a user is the closest to the Wi-Fi router (Reference point A in Figure 4 (Right)), the signal strength will be the strongest. When a user is the farthest from the Wi-Fi router but still in the room (Reference point Bs in Figure 4 (Right)), the strength will be the weakest within the room. When a user is right outside of the room door (Reference point C in Figure 4 (Right)), the strength will be the strongest from possible points outside of the room. We collect signal strengths (RSSIs) at all of those reference points in each six rooms on the floor. Figure 5 shows our example output of Wi-Fi scanning.

Network Name	BSSID	Security	Protocol	RSSI	Channel
eduroam	**04:bd:88:3b:77:b0**	**WPA2 Enterprise**	**802.11ac**	**-32**	**48**
LeopardGuest	04:bd:88:3b:77:b1	Open	802.11ac	-32	48
eduroam	04:bd:88:3b:77:a0	WPA2 Enterprise	802.11b/g/n	-33	6
LeopardGuest	04:bd:88:3b:77:a1	Open	802.11b/g/n	-36	6
eduroam	04:bd:88:1e:b9:c0	WPA2 Enterprise	802.11b/g/n	-54	11
LeopardGuest	04:bd:88:1e:a8:e1	Open	802.11b/g/n	-55	1
LeopardGuest	04:bd:88:1e:a8:f1	Open	802.11ac	-58	36
eduroam	04:bd:88:1e:b9:a2	WPA2 Enterprise	802.11b/g/n	-63	6
LeopardGuest	04:bd:88:1e:b8:e1	Open	802.11b/g/n	-66	1
LeopardGuest	04:bd:88:1e:b0:01	Open	802.11b/g/n	-70	11

(a) Wi-Fi Scanning result at reference point A

Network Name	BSSID	Security	Protocol	RSSI	Channel
eduroam	04:bd:88:3b:77:a0	WPA2 Enterprise	802.11b/g/n	-36	6
eduroam	**04:bd:88:3b:77:b0**	**WPA2 Enterprise**	**802.11ac**	**-42**	**48**
LeopardGuest	04:bd:88:3b:77:b1	Open	802.11ac	-42	48
LeopardGuest	04:bd:88:3b:77:a1	Open	802.11b/g/n	-48	6
eduroam	04:bd:88:1e:b9:c0	WPA2 Enterprise	802.11b/g/n	-56	11
eduroam	04:bd:88:1e:b8:e0	WPA2 Enterprise	802.11b/g/n	-59	1
eduroam	04:bd:88:1e:a8:f0	WPA2 Enterprise	802.11ac	-63	36
LeopardGuest	04:bd:88:1e:a8:f1	Open	802.11ac	-63	36
LeopardGuest	04:bd:88:1e:b9:c1	Open	802.11b/g/n	-64	11
eduroam	04:bd:88:1e:a8:e0	WPA2 Enterprise	802.11b/g/n	-65	1

(b) Wi-Fi Scanning result at reference point B

Network Name	BSSID	Security	Protocol	RSSI	Channel
eduroam	**04:bd:88:3b:77:b0**	**WPA2 Enterprise**	**802.11ac**	**-38**	**48**
LeopardGuest	04:bd:88:3b:77:b1	Open	802.11ac	-38	48
LeopardGuest	04:bd:88:3b:77:a1	Open	802.11b/g/n	-40	6
eduroam	04:bd:88:3b:77:a0	WPA2 Enterprise	802.11b/g/n	-44	6
eduroam	04:bd:88:1e:b9:c0	WPA2 Enterprise	802.11b/g/n	-57	11
LeopardGuest	04:bd:88:1e:a8:e1	Open	802.11b/g/n	-61	1
eduroam	04:bd:88:1e:a8:e0	WPA2 Enterprise	802.11b/g/n	-64	1
LeopardGuest	04:bd:88:1e:b5:20	Open	802.11b/g/n	-64	11
LeopardGuest	04:bd:88:1e:b8:e1	Open	802.11b/g/n	-64	1
eduroam	04:bd:88:1e:b9:70	WPA2 Enterprise	802.11ac	-65	44

(c) Wi-Fi Scanning result at reference point C

Figure 5: Example Outputs at Reference Points.

As shown in Figure 5, reference point A gets the strongest RSSIs. From our testing, the RSSI at A varied from -26 to -42 dBm. At reference point B, the RSSIs varied from -32 to -45 dBm. This room boundary RSSI is the most important in this solution. At reference point C, the RSSIs varied from -37 to -49 dBm. From the testing, we found that the user will have a RSSI no lower than -45 dBm in the room.

D. Finding Room Number with MAC Address

When the user scans Wi-Fi signals with Airport (Wi-Fi Scanning Tool), the output will be saved in a Plist. Then we need to extract BSSID (MAC address) and RSSI from the Plist and convert them into an array in Python as shown in Figure 6. Then our system finds the strongest RSSI scanned and looks up the room number with MAC address. If the RSSI is equal to or higher than -46 dBm, our system shows the matching room number. Otherwise, our system shows the floor information.

```
for count in range(0, 1000):
    airport = "/System/Library/PrivateFrameworks/Apple80211.framewor
    subprocess.check_output(airport, shell=True)
    # os.system("clear")

    pl = plistlib.readPlist('airport.plist')

    routers = []
    for router in pl:
        digits = []
        for digit in router['BSSID'].split(':'):
            if len(digit) == 1:
                digit = "0" + digit
            digits.append(digit)
        router['BSSID']=":".join(digits)

        routers.append({
            'ssid'      : router['SSID_STR'],
            'bssid'     : router['BSSID'],
            'rssi'      : int(router['RSSI']),
            'channel'   : int(router['CHANNEL'])
        })

    routers = sorted(routers, key=itemgetter('rssi'), reverse=True)

    for n in range(0,len(routers)):
        if routerdict.get(routers[n]['bssid']):
            if routers[n]['rssi'] < -46:
                print routerdict.get(routers[n]['bssid'])[0:6]
            else:
                print routerdict.get(routers[n]['bssid'])
                pp.pprint(routers[n])
            break;
    print "rescanning %d" % count
```

Figure 6: A Snippet of Python Script.

E. Testing

During the first 50 second testing, there were 14 scans for 4 rooms. One of the scans was recognized too early when the nearest router had a strong signal. Besides that, 13 of 14 scans worked as expected. The error rate was 7.1%. For a 120 second demo, there were 35 scans for 6 rooms. The error rate of demo 2 was 51%. 8 errors were interrupted by other nearby rooms and 5 errors showed delayed locations. 4 errors occurred because the prototype received weak signals from the nearest rooms.

Figure 7: Screenshots of Demos. (Left) Prototype guessing the correct location of WENTW 307. https://youtu.be/ue4B3pu2XXE (Right) Prototype not recognizing the location near WENTW 310. https://youtu.be/iH86sBqyPWA

F. Analysis

Based on the above testing results, *Telepubbies* demonstrated its ability to detect the user's golocation by using the signal strengths from surround Wi-Fi rounters. Although there are some limitations, the prototype system:

- ***Works perfectly in a room:*** the boundary RSSI value provides useful information to determine which room the user is in.
- ***Has a low accuracy in the hallway:*** Since we did not include any reference points in the hallway and we had different numbers of moving obstacles (students), the second demo showed a poor accuracy. In addition, different room shapes and signal noises from other floors are possible factors to lower the accuracy.

III. CONCLUSION AND FUTURE WORK

The GPS system has changed people's life dramatically, but it still has a difficulty to be easily used in an indoor or mid-scale environment, such as school campuses or buildings. In this paper, we study on this issue and propose a novel system, *Telepubbies*, to address this issue. The system uses Wi-Fi routers and a new customized algorithm to support object positioning in an indoor or mid-scale environment. Because the proposed solution is simple and there is no need to change or modify existing Wi-Fi layout in the environment, the undergraduates also can learn about Wi-Fi positioning system with hands-on learning activities.

Telepubbies system has a high portability. It uses RSSI fingerprinting method that is simple and easy to be implemented in different environments. Two information are needed for our algorithm: (1) a list of MAC addresses, and (2) room numbers. If the user is in a room and the room number is known, the RSSI method can work perfectly. However, if the user is not in the room and we want to specify his/her location in the hallway, the RSSI method needs an extension of other implementations, such as the triangulate method or more reference points in the hallway.

There are two ideas to improve the accuracy of positioning. First, in order to find the exact boundaries for each room, more Wi-Fi scans at various points are required. The various points include both inside and outside of each room's door. Second, we can also create a program to collect and measure Wi-Fi signals from Wi-Fi interface directly.

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