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EXPERIMENTAL TESTS FOR NON-INTRUSIVE TRAVEL DEMAND DATA COLLECTION EMPLOYING Wi-Fi SENSING

PART 2

Marius MINEA[1], Ionuț-Cosmin CHIVA[2]*, Viviana Laetitia MINEA[3], Augustin SEMENESCU[4]

This paper presents the second part of a research on the possibility to collect anonymous data regarding the level of service in public transport and indoor localization/route guidance. Wireless technology (Wi-Fi) is employed to detect, and trace mobile devices carried by travelers. A study on the wireless propagation in different environments, such as metro stations and trains has been performed, in order to determine a theoretical model and an optimal placement of sensors. The solution can also serve as back-up system for locating vehicles on their path. Due to the complexity and extension of the subject, the paper has been divided in two parts. The first part of the paper presented the overall solution proposed, a study on the state of art, conditions and models regarding Wi-Fi signals propagation, accompanied by a first set of experimental tests. The second part of the paper is focusing on a deeper research on the conditions of propagation, including the analysis of latency and influence of people on platforms on the signals propagation. Also, the overall architecture of the proposed system and a new model for indoor propagation in underground metro stations are provided.

Keywords: Anonymous data collection, Wi-Fi signals propagation, wireless sensing, indoor propagation modeling, signal attenuation, latency

1. Introduction

The present article is a continuation of a set of experiments that have been performed in a subway station to evaluate the conditions of indoor signals propagation, specifically for the Wi-Fi channel 1 (2.4 GHz band), as support for a solution to anonymously determine the flowing of passengers in similar environments. The state of art and a literature review in this domain has been presented in the first part of this article. References [1] to [15] were described in

[1] Associate Professor, Transports Faculty, University POLITEHNICA of Bucharest, Romania, e-mail: marius.minea@upb.ro
[2] PhD Candidate, Eng., University POLITEHNICA of Bucharest, Romania, corresponding author, e-mail: cosmin373@yahoo.com
[3] CRM Applications Administrator, Orange Romania SA, e-mail: mineav08@gmail.com
[4] Professor, Materials Science and Engineering Faculty, University POLITEHNICA of Bucharest, Romania, e-mail: augustin.semenscu@upb.ro

the dedicated section from this part of the paper. Therefore, this paper will focus only on practical aspects regarding the measurements performed, the new model proposed for propagation and the description of the architecture which is proposed for the data collection system.

Regarding the radio waves propagation medium, in this case there are several conditions that have to be taken into consideration, due to the specificity of the environment, such as the station or tunnel geometry, walls' materials composition, variability of the number of people in the signal's propagation area, number of active Wi-Fi and/or BT devices on site, and so on. A continuation of the specific tests is described in this paper and most relevant results presented. A model for the signal propagation conditions, developed from the classic indoor propagation models is also provided and compared with the measured values. RSSI levels have been determined and described in the first part of these articles and were performed in Unirii subway station – Bucharest, Romania. Also, a practical solution for data collection useful for public transport management is presented in the final part of this paperwork.

2. Field Experimental Tests

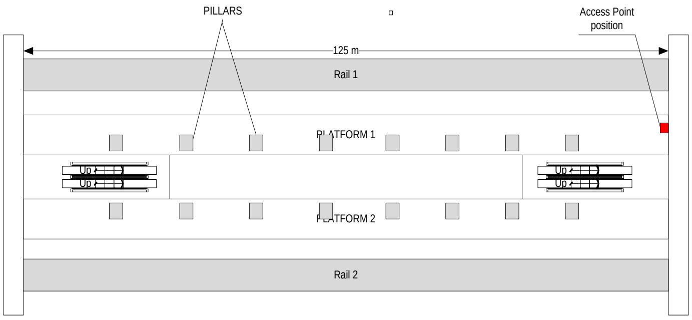

Fig. 1. Overall setup of the testing environment

In order to deeper explore the propagation conditions, a set of initial calibration tests have been performed in an open-field area, outside the subway station, for assessing the characteristics of the equipment. The collected data also served as a reference for the indoor environment measurements. In the subway station the AP was placed near a wall at one end of the station (Fig. 1), and a mobile phone with dedicated software was placed at different distances from the AP, to determine RSSI evolution, latency and data transfer speeds. Three scenarios were taken into consideration:

- Open field (FOV) measurements – variation of RSSI, data speed and latency;

- Indoor measurements for the same parameters without people on subway platforms (only to determine the influence of the environment geometry: walls, pillars, platforms, and other elements).
- Indoor measurements for the above-mentioned parameters with travelers on platforms (to determine the influence of persons on the platforms on the signals propagation, channel throughput and latency).

Aside from measuring connection speeds, the tests in the three environment scenarios included also the variation of latency and RSSI, according to distance from the access point. These parameters are considered useful if a future system for indoor route guidance will be based on triangulation to different APs, in the subway environment. Distance steps of 12 meters from the access point were established for each measurement, and for each step were made three separate measurements, for reducing the variation of signal intensity due to different interferences and propagation conditions variation. Afterwards, the average value was considered for building the following diagrams:

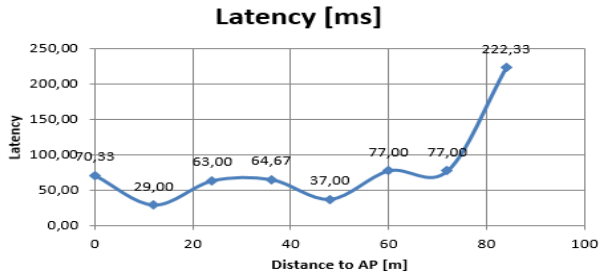

Fig. 2. Variation of latency with distance, open space

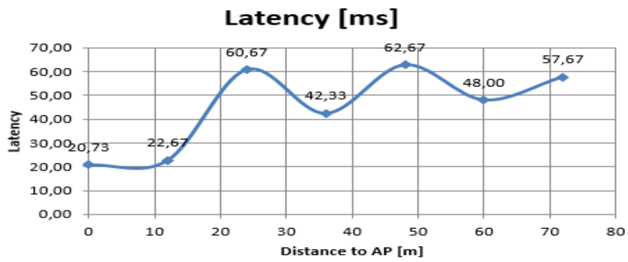

Fig. 3. Variation of latency with distance, inside subway station, no travelers on platforms

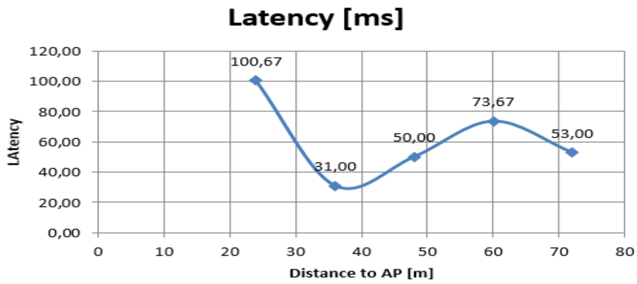

Fig. 4. Variation of latency with distance, inside subway station, people on platforms

The average data speeds recorded in the above-described conditions are presented in Table 1.

Tabel 1

Average values of some measurements

Conditions	Average download speed [Mbps]	Average upload speed [Mbps]	Average latency [ms]
Direct FOV	26.47	15.20	80.04
Inside station – no travelers on platforms	30.55	6.60	44.96
Inside station – many travelers on platforms	9.11	6.02	61.67

The lower average value for the download speed in direct FOV conditions may be explained by the presence of numerous access points in the zone where measurement took place, reducing channel throughput. It can be observed that the station environment favors in a certain amount the data speed by shielding the outside field generated by different APs. When travelers carrying active mobile devices enter the station, the data speed worsens significantly.

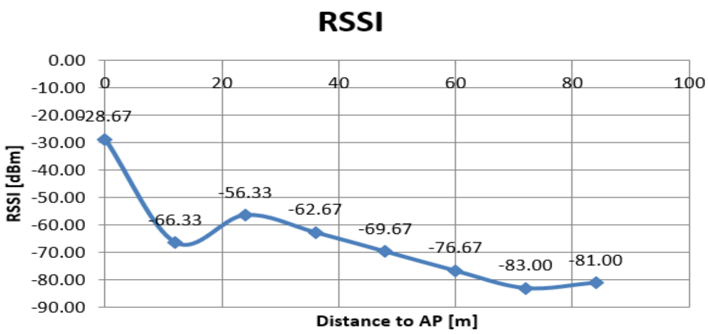

Fig. 5. Variation of RSSI with distance, open space

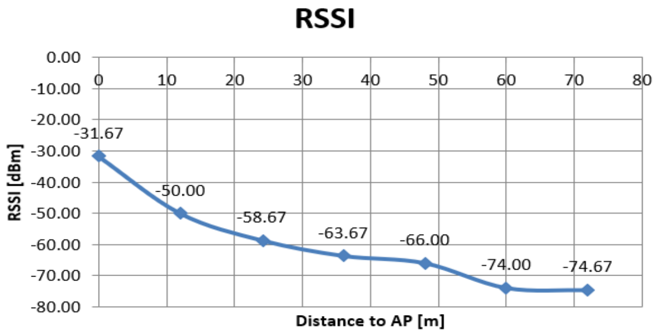

Fig. 6. Variation of RSSI with distance, inside subway station, no travelers on platforms

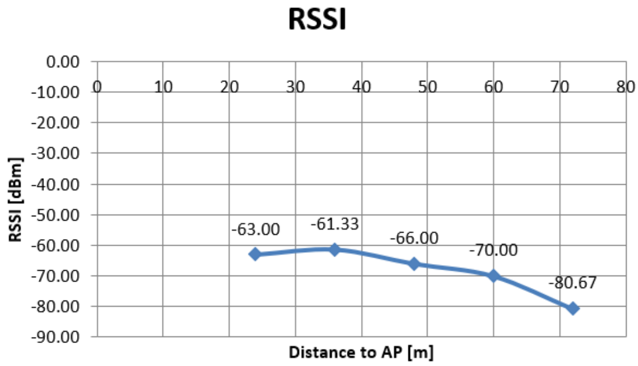

Fig. 7. Variation of RSSI with distance, inside subway station, people on platforms

In Figs. 4, 5, 6 and 7 the RSSI levels are presented comparatively in different situations: Figs. 4 and 6: same test conditions, one week later (no travelers on platforms). The average RSSI values are -73.08 dBm and -59.81 dBm. It appears that the most appropriate distance between APs should be around 35 meters, with a ±5 meters tolerance, for a good reception level, as stated before.

For a more accurate evaluation of the influence that the passengers on the platforms have on the propagation conditions, the next set of measurements has been performed at a peak hour in the same subway station. Test conditions: AP set on Channel 1, in the 2.4 GHz band. The access point was placed near an end of the platform and the following set of tests has been performed:

1. Determining the variability of parameters according to the number of persons sitting on the platforms, at different distances from the AP;
2. Determining the variability of parameters in stationary location, with different number of passengers on platforms – this feature may affect the accuracy of indoor location.

The results of this set of field measurements are presented in the following diagrams.

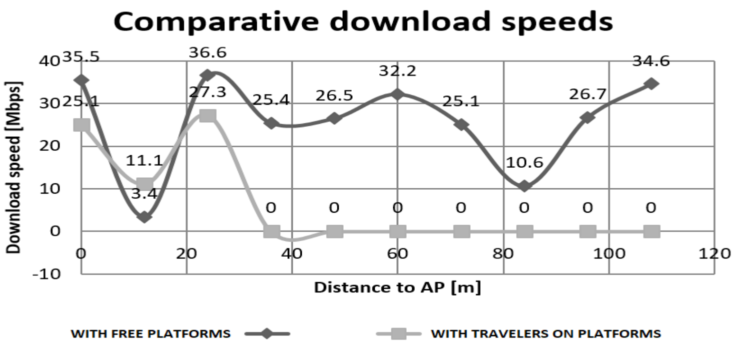

Fig. 8. Influence of people presence on the platforms on the download speeds

As it can be observed in Fig. 8, the download speed is most affected when the platforms are full of people (square-dotted curve), and after around 40 meters from the access points, practically the connection was lost. At 15 meters from the AP, the drop of the signal in both situations was caused by the arrival of a metro in the station.

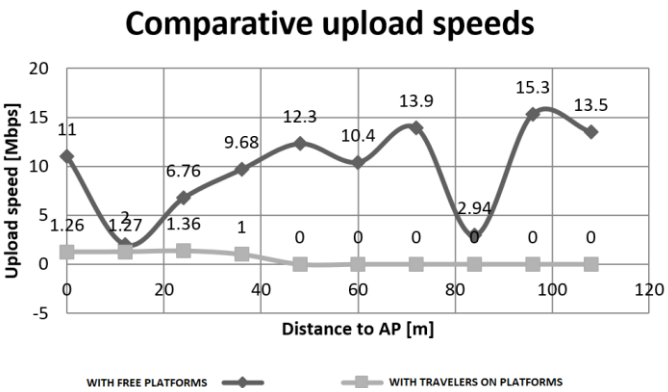

Fig. 9. Influence of people presence on the platforms on the upload speeds

In Fig. 9 is presented the variation of upload speeds in normal and agglomerated conditions (with many travelers on platforms). It can be noticed that the download speed drops dramatically when there are many people on platforms (square-dotted line on the diagram), compared to usual situations, with a variable number of people in the station. As in the previous case, the two low peaks were recorded when trains arrived in the station, at rush hours, with many travelers.

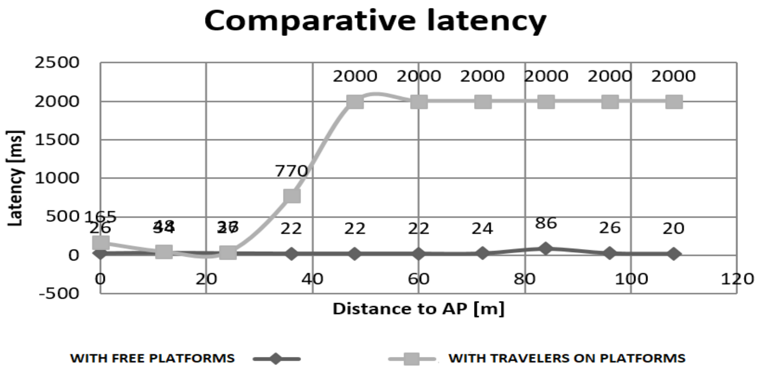

Fig. 10. Influence of people presence on the platforms on the latency

Fig. 10 presents the variation of latency in two different cases – dotted line – evolution in stationary normal conditions, with variable number of people on platforms, square-dotted line – evolution in case of crowdy platforms. It appears that the latency suffers most because the variation of the number of people sitting on the platforms. If a “time of flight” (TOF) location system is employed for indoor localization using Wi-Fi, this observation might significantly affect the precision of the location. Since in the real tests, the values received for distances larger than 40 meters were exceeding several seconds, a 2000 ms value was artificially set to better represent the diagram, otherwise for the real values overpassing many seconds the two devices eventually did not connect.

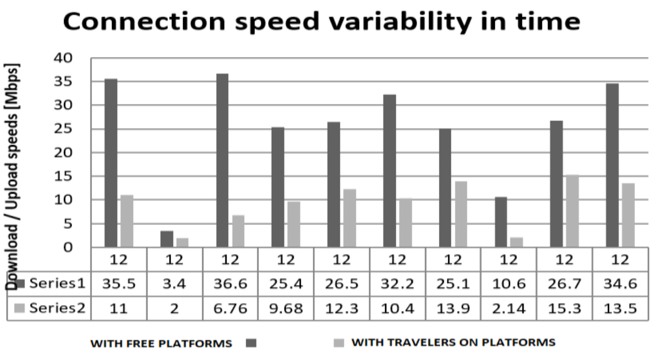

Fig. 11. Comparative measurement of connection speed –
stationary position, constant distance to AP

Grey colored bars indicate the situation with many travelers on platforms – the connection speed decreases significantly.

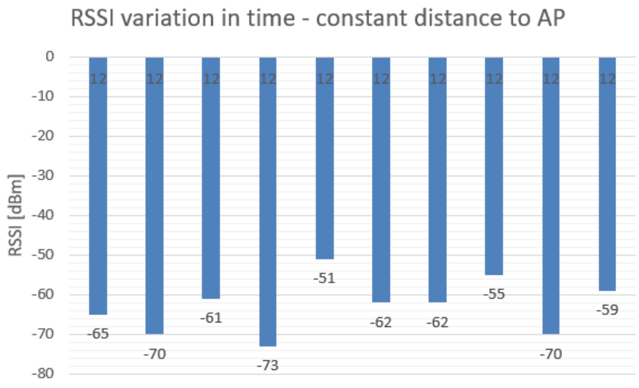

Fig. 12. Comparative measurement of RSSI – stationary position, constant distance to AP

A. Conclusions of the Field Tests

Young and promising, wireless technologies for anonymous data collection have the advantage of simple infrastructure equipment [1], [3], [4]. The access points, able to collect information like MAC addresses, timestamps and RSSI levels are enough to collect important quantities of information. A more difficult part is represented by the filtering and data mining when enough information has been collected in a dedicated database. Anyway, the proposed solution does not offer neither direct, nor exact results. But it has the ability to self-improve in time, when the collected data becomes more and more consistent. For the case study performed in Bucharest conditions, it resulted that for the moment, a relative low percentage of persons carry detectable Wi-Fi or BT devices: around 4.7%. This does not yet fulfill the conditions of a critical mass, but it is expected that in a near future, with the fast development of mobile Internet, smart devices and connectivity, the number of detectable nodes will increase significantly.

3. Designing the Architecture of the Travel Demand Data Collection System (TDS)

Considering the experimental results from the first part of this article, the paperwork [1], and those presented above, it can be concluded that an architecture of a travel demand data collection system employing wireless anonymously data collection solution should be comprised of (but not limited to):

- A network of wireless APs, employed as sensors for Wi-Fi enabled devices;
- A local server for collecting, storing and local processing data;
- A workstation (not mandatory);
- Interface with the Internet via a VPN and possibility to connect to a Data Center and to remotely access the local system.

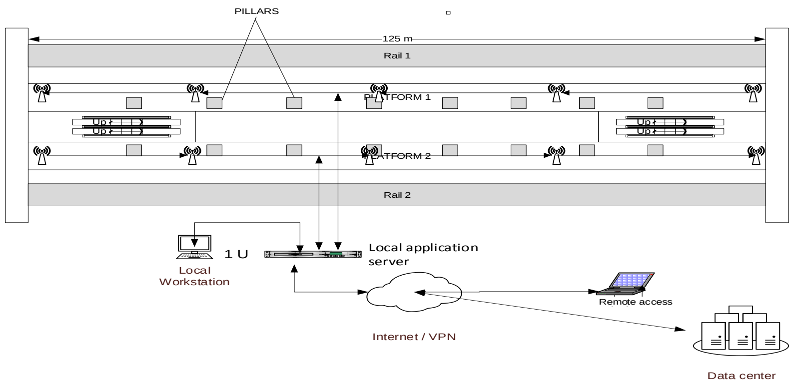

Fig. 13. Proposed architecture of the TDS

The architecture is presented in the above diagram. The distance between the APs has been established according to the measurements at 35 meters apart each other. For the applications designed to use APs as geographical reference points, the indoor localization protocol will need a dual communication (transmission and reception of messages) between the APs and the mobile devices that need localization and a broadcasting protocol. Therefore, the true geometrical position according to the station configuration should be as part of the broadcasted message of each AP. This information, along with TOF (time of flight / RSSI level) will then serve in a process of triangulation to determine the actual position of the mobile device indoors. Future developed applications for virtual / augmented reality could then help travelers rapidly find their path to the desired destination. Also, another possible application would be to determine an approximate regarding the number of travelers in each wagon of the metro, versus the wagon’s designed capacity. In this way, the passengers waiting on the platforms could be directed to less agglomerated wagons.

4. Adaptation of the Existing Models for Indoor Propagation

Considering the tests that have been performed for the Wi-Fi propagation inside the subway station, the following factors have been found to influence the path loss of the signal:

- The materials and composition of the walls and floor;
- The presence and number of persons sitting on the platforms;
- The existence and usage of mobile devices with Wi-Fi (mobile phones, notebooks);
- The geometry of the station, dimensions and number of pillars, materials.
- A series of other, random factors, such as the presence and number of persons on the platforms.

Of course, a very realistic model is difficult, or even impossible to determine for the path loss, due to the variability of conditions [8], [9], [10].

However, a good representation of the attenuation in these conditions has been obtained, after several attempts, with the Friis model from equation below.

$$PL = 20log_{10}(\frac{4\pi d}{\lambda}) \tag{10}$$

where d represents the distance from the AP and λ is the wavelength.
Other models that have been tested were ITU-R, Tata Indoor Path Loss Model (TIPLM) [14].
To represent the randomly variating effects of the above-mentioned factors, the Friis propagation model has been adapted in the following form:

$$PLad = 20log_{10}\left(\frac{4\pi d}{\lambda}\right) + 9 \cdot \xi \cdot WP_{IF} - 10 \tag{11}$$

where ξ represents a random factor modeling the variable conditions caused by the presence of people on platforms and usage of additional Wi-Fi connected devices, and WP_{IF} is a factor depending of the walls shape and composition and pillars present in the subway station. There have been tested several values for WP_{IF} factor and the most convenient for the case of Unirii station has proved to be 1.2.

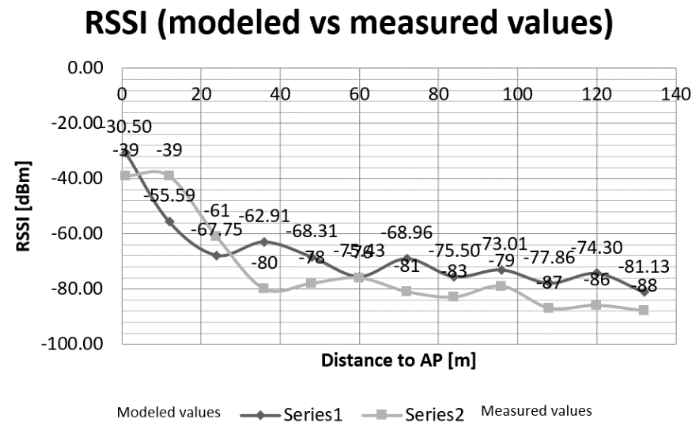

Fig. 14. Comparison between modelled
signal loss (black line) with measured values (grey line)

5. Conclusions

A. Purpose of work

The purpose of this work has been to study, in real life conditions, the radio signals propagation behavior in a typical environment of a subway station, with important passengers flowing. It has been observed that the environment geometry considerably affects the way the radio waves propagate. Firstly, a slight waveguide effect is being present, prolonging the reception distance, compared with free open space conditions. Secondly, the quality of the link (upload/ download speeds) is seriously influenced by the number of mobile nodes present in the reception area, and by the persons themselves, causing a drop in the channel throughput, resulting in reducing the speed of the datalink. An average distance of around 30-35 meters between the successive APs has been noticed as being optimal, in case a network of such “sensors” is to be deployed in the subway station environment, in order to maintain the reception level above -60 dBm. These “sensors” may record MACs, timestamps and location of the detected mobile devices, giving the opportunity to determine origin-destination of passengers anonymously. Of course, there is also the variability of levels that might be also dependent on the equipment manufacturer, position of antennas, or other relevant elements. These factors have not been considered for this modeling.

B. *Future work*

The solution proposed by the authors is considered simple and efficient from the point of view of the necessary infrastructure hardware, thus significantly reducing the cabling, power supplying and maintenance of the network of sensors. Specific Access Points installed in selected locations may determine the number of detectable Wi-Fi and / or BT devices present in the station. MAC addresses, along with time stamps and location stamps can then be collected and a database populated with this information. A specific, AI-powered software takes afterwards the role of extracting information of interest, such as:

- Estimating the number of travelers passing in the detection zone;
- Building matrixes of origins and destinations and associating flowing of passengers between these, an instrument to dynamically manage the number of trains on a route;
- When acting like reference APs, the devices may be used for indoor location reference points and may be further be employed as pinpoints for a virtually augmented reality, in a service for route guidance of travelers.

As future work, the authors proposed themselves to continue testing the Bluetooth technology in the same environment and conditions, where more representativity than Wi-Fi has been noticed amongst travelers and passengers (connected devices that are detectable include: smartwatches, BT headphones, notebooks, tablets, TV sets). The results of these tests are hoped to deliver enough information regarding the usability and efficiency of the proposed methodology for determining transport demand in congested urban areas.

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