User’s Macro and Micro-mobility Study using WLANs in a University Campus

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Abstract — **Wireless Local Area Networks are important and necessary in university campuses and large enterprise areas. Such networks allow us to have data connection anywhere without wires and many other benefits such as to obtain the location of the users. Moreover, they can be used to track the users. Tracking the user’s mobility we can know which places are most visited, if people have to go to places that are far from their office, detect the best location for emergency points, etc. Moreover, we can study the mobility pattern of several users. According to this pattern, the network can use reconfiguration systems to reallocate resources and improve its connectivity. This paper shows us the case study of a university campus of two square kilometers and how we have taken advantage of the information gathered from the wireless network. Two studies (macro and micro mobility) have been done in order to make this survey. This approach can be used by the enterprises to optimize the sites to place their resources (network printers, servers, meeting rooms, etc.). Furthermore, the network’s administrators can use these parameters to improve the network’s behavior by providing a better connection, better roaming, etc.**

Keywords - People Mobility; macro-mobility; micro-mobility; people tracking; WLANs

I. INTRODUCTION

Nowadays, wireless local area networks are widely implemented. The public organisms such as universities, governments, etc. are well known examples. These wireless networks are usually based on the IEEE 802.11 b/g standard [1]. The standard presents many advantages. We can emphasize some of them:

- The use of a free band in the 2.4 GHz.
- Speeds up to 54 Mbps.
- The user’s comfort is bigger than in wired networks.
- Wireless networks allow the access of multiple computers with a smaller infrastructure cost.
- The compatibility among different devices is very high, because of the organization Wi-Fi [2].

The IEEE 802.11 b/g networks present the intrinsic problems of any wireless technology. Some of them are:

- The wireless connections bandwidth is smaller than in wired connections.
- Wireless connections are more prone to be attacked because they can be accessed from anywhere, although there are several methods to encrypt the communication.
- The roaming can stop any communication between the devices of the network.
- WLAN is not compatible with other wireless technologies like Bluetooth [3], UMTS [4], etc.

The wireless LAN network is mainly used to transmit data, but there are many other applications. One of the most well known applications is the indoor positioning system. The localization is made using the access point’s received signal strength and the use of different mathematical methods is possible [5]. There are many other applications such as providing connectivity in meetings, wireless VoIP, wireless IPTV and so on. Most of them are a service guided to end-user.

In this paper, we use the data obtained from the WLAN in order to study the mobility of the users. The roaming information can be used to know the behavior of the people in a place, to relocate the bandwidth and how they move from one building to another. This information will let us know the movement of the users, what buildings are most visited, etc.

We will study the mobility from several points of view: macro-mobility, that relates to the behavior of users between buildings and big areas, micro-mobility that relates to the movement of users inside a building and from that data we will extract the attractor points of the area, that are the focal points that have to be considered for the movement of people.

This paper is based on a previous work [6] presented by the same authors. In this paper we have added a micro mobility study and improved several main parts of that conference paper.

The paper is organized as follows. In Section 2, we discuss the related work about mobility tracked by wireless networks. Section 3 explains our university wireless network. Section 4 describes the steps performed to gather mobility data. Macro-mobility and people tracking measurements can be observed in Section 5. Section 6 is devoted to micro-mobility and what is the mobility profile of mobile users in our wireless network. Moreover, we show the behavior of a regular user. Finally, Section 7 presents our conclusions and future work.

II. RELATED WORK

We have found several works related to people mobility and tracking.

In [7], Z. Chen et al. presented a system that works like an indoor GPS. It uses RFID and provides directional instructions for users while tracking things. It is called DynaTrack and consists of three key parts which are the RFID tags and readers, database servers that hold information about things’ location and the DynaTrack client side interface. This system uses a dynamic or static system tags, depending on if it is an object or a person. Also, they tell us that if an object, initially labeled as static, begins to move, the system is able to change its address dynamically.

Another example of a tracking system is presented by J.G. Markoulidakis et al. in [8]. In this paper, we can see a new system based on Third Generation Mobile Telecommunication Systems (TGMTS) and the three basic types of mobility models that are appropriate for the full range of the TGMTS design issues. They propose a methodological modeling approach called Integrated Mobility Modeling Tool (IMMT). IMMT tries to improve some aspects of other systems like the validation of the theoretical input assumptions and analytical models or the effect of the mobility model accuracy.

The authors in [9] show the possibilities of utilizing RFID, Wi-Fi and Bluetooth wireless technologies to determinate their limitations in personnel/equipment tracking and mapping mine works of Pollyanna (underground mine in Oklahoma). Other wireless technologies, as the conventional satellite GPS technology, are not feasible there. They evaluate the advantages in the real-time location services (RTLS) technology to determine their applicability and limitations to underground mining at the Pollyanna.

In [10], B. Issac et al. presented a predictive mobility management system which could make mobility on an IEEE 802.11 network more proactive with minimum loss and delay, when compared to existing schemes. Their proposal is focused on WLAN installations within a restricted campus and to predict the mobility path of a mobile node and use that information to lessen the handoff delay.

A wireless indoor tracking system, based purely in software because no additional hardware is required, is described in [11]. It can be used to track and locate both moving and static WLAN-enabled devices inside a building. The system uses complex mathematic algorithms and determines the locations of the mobile devices according to the received signal strength from visible access points. The author categorizes the WLAN-based location determination algorithms, into two groups: deterministic and probabilistic algorithms. Finally, the paper is concluded making some reflections about the number of APs and their correct localization in order to obtain reliable results.

There are other works that show a study and even try to imitate the human behavior movements through simulations. One of them is the paper presented by T. Liu et al. in [12]. They present a model in order to mimic human movement behavior. It is built as a two-level hierarchy in which the top level is the global mobility model (GMM): a deterministic model that is used to create intercell movements and the bottom level is the local mobility model (LMM): a stochastic model with dynamically changing state variables to model intracell movement.

Another example of a human behavior simulation is given in the paper presented by C. Bettstetter [13]. It shows a model that can be used in simulations of mobile and wireless networks. He uses a combination of principles for direction and speed control to provide the movement of the users. It shows the calculation process to simulate changes of speed, stop-and-go behaviors or address control, among others.

In [14], the authors present a general methodology for obtaining the mobility information from wireless network traces, and for classifying mobile users and APs. In order to develop this methodology they use Fourier transform and Bayes' theory. The authors find some relations between several parameters, but in their study they say that the data is too variable because it depends on seasonal cycles, trend, regression term and irregular effects.

In [15], J. Gosh et al. analyze a yearlong wireless network users' mobility by tracing the data collected. They propose an efficient method to determine the main mobility profiles of a user using a mixture of Bernoulli's distribution. This method allows the authors to predict from 10% to 30% of the user's mobility.

In summary, the works presented previously carried out studies only related with users' tracking, except for [12] and [13] that develop simulation models of people's mobility. In all of these previous papers, the buildings are considered as passive objects (they do not give information). In contrast, in our work, each building is considered a group of several APs, and we use these groups to see the user's mobility around our university. With these data we could relocate some services and the displacement of the users would be more efficient.

III. Wireless Network Description

The Universitat Politècnica de València (UPV) is distributed on three Campuses. One of them is located in Valencia and contains about 80% of the students and staff of the University. It has a dimension of about three kilometers long and one kilometer wide. There are two smaller campuses in the nearby cities Gandia and Alcoy. There are around 4,000 researchers and educational personnel, around 1,500 staff and around 36,000 students among the three campuses. The distribution of students in each faculty is shown in Table I.

On these Campuses, a wireless IEEE 802.11 b/g network is deployed. It comprises more than 575 access points to get full coverage, including not only the buildings and offices, but the surrounding gardens and open space between these buildings. So, any person in the UPV can roam seamlessly between any locations. The distribution of these access points is: 33 APs are in the Campus of Gandia, 42 APs are in the Campus of Alcoy and 500 APs are in the main Campus (Campus de Vera). The APs are installed to allow the users a continuous coverage as they roam throughout a facility. The coverage of each access point varies between 30 m at 54 Mbps and 137 m at 1 Mbps for indoor environments.

The access points are from Cisco Systems Inc. (models 1130, 1140 and 1300) and they are configured with three simultaneous SSIDs, one with VPN authentication, another one with 802.1X authentication and the last one interacted into the EDUROAM (European roaming project) for visitors. Any member of the University, and from others via EDUROAM, has free access to that wireless network.

TABLE I. PEOPLE REGISTERED IN EACH BUILDING

Building	People registered
E. Politecnica Superior de Alcoy	2298
E.T.S de Ingenieria de Informatica	3240
E.T.S. de Arquitectura	3858
E.T.S. de Gestión de la Edificación	2920
E.T.S. de Ingenieria del Diseño	4794
E.T.S. del Medio Rural y Enología	1074
E.T.S.I. de Agronomos	1841
E.T.S.I. de Caminos, Canales y Puertos	3145
E.T.S.I. de Telecomunicación	1409
E.T.S.I. de Geodesica, Cartografía y Topología	1027
E.T.S.I. de Industriales	3479
E. Politecnica Superior de Gandia	2320
F. de Administración y Dirección de Empresas	2271
F. de Bellas Artes	2334
Total	**36010**

IV. PEOPLE TRACKING MEASUREMENTS

It is quite complicated to predict if the students will visit more times some buildings than others. This study could be used to relocate some schools and services in order to obtain a more effective and efficient distribution or even to help planning the construction of a new university. In this section, the measurement process will be explained in order to analyze the number of users' change between buildings. Baseline measurement

In order to gather information from the wireless network, the SNMP agent was activated in all wireless APs using only the required messages. Every time a MAC address is associated to an AP, it sends a SNMP trap message to a central server. This information is stored in a database to be processed and analyzed.

First, APs are grouped according to the building where they are placed. This activity was not difficult because in our university each AP has a unique identifier, formed by the name from the building and the MAC address. All the APs in a building can be grouped easily using the same badge.

The database contains several tables in order to analyze the information. There is a table that stores the day and the month of the information jointly with the AP DNS name and the MAC that has been associated. Another table relates every access point with the building where it is placed. These tables allow us to make several queries such as:

- MACs registered
- Buildings with wireless access points
- MACs in every building
- MACs in every campus
- MACs that roam between buildings
- MACs that roam between buildings every day
- MACs that roam between buildings every month
- MACs associated to every AP during a day
- MACs associated to every AP during a month
- APs in every building
- APs where each MAC has been associated in a day
- APs where each MAC has been associated in a month

As we have said before, in this paper we are going to do a study where we analyze the macro-mobility and the micro-mobility. Knowing this starting point we will treat the data in different ways. Firstly we will group the associations that occurs in each building (macro-mobility), on the other hand we analyze the MAC addresses, which travel more and which are the access points with more visits. In order to process the information recollected in the database, we have used several SQL queries to extract the data needed and then we analyze the mobility of users.

Moreover, when we have selected the data, we have used a spread sheet to calculate some parameters as average number of visits in a building, percentage of visits, etc. With this spread sheet we have made some figures to represent better the information collected.

V. MOBILITY BEHAVIOUR OF USERS BETWEEN BUILINGS (MACRO-MOBILITY)

In this section, the macro-mobility in our campuses will be studied. In this part of the study we analyze the mobility between buildings and campuses, besides we try to describe the people behavior using these data.

A. Data processing

The people tracking measurement process is based on the number of people roaming among buildings. It is also measured where the people stop during a period of time. These measurements let us know the quantity of movements among all the buildings in the campus. In order to estimate the time that a user takes to go from the A building to another B building, we keep in mind that it could be the C building inside this itinerary. Roaming will exist among the A building, the C building and the B building, but the displacement will be considered from the building A to the B building. This study cannot be considered as a system of privacy intrusion, because this system does neither save a correspondence list of each person, nor their MAC addresses. Only the amount of movements is interesting. Moreover, the MACs used in this study are not real. The system changes a real MAC to another one (fictional) to preserve the privacy of people

Once all APs of each building have been grouped, the roaming among the APs of the same building will not be taken into account because these movements are inside the same building and the user does not move among buildings.

All these data has been stored in a database during a month to carry out this study. Firstly, the data have been purified because there was some information that was not useful to this study. These data have been taken daily and, therefore, we can show the information gathered during a regular day or show the information about monthly activity.

In order to process the data we have used a spreadsheet Excel 2007 with the NodeXL tool [16]. NodeXL is an extendible toolkit for network overview, discovery and exploration. The core of NodeXL is a special Excel 2007 workbook template that structures data for network analysis and visualization. Six main worksheets currently form the template. There are worksheets for “Edges”, “Vertices”, and “Images” in addition to worksheets for “Clusters,” mappings of nodes to clusters (“Cluster Vertices”), and a global overview of the network’s metrics (“Overall Metrics”).

As we will see in the following section, this software tool allows visualize the roaming among the buildings, the quantity of roaming made, filter the quantity of roaming, etc. NodeXL is a powerful tool that can help us analyze the behavior of the network. NodeXL aims to make analysis and visualization of network data easier by combining the common analysis and visualization functions with the familiar spreadsheet paradigm for data handling. The tool enables essential network analysis tasks and thus supports a wide audience of users in a broad range of network analysis scenarios.

B. Roaming during a day in the Vera Campus

Table II shows the numbers of changes among the buildings in one day. The rows represent the number of users that roam from that building to another. The situations where there is no mobility among a pair of buildings, that is, there is no MAC roaming between that two buildings in a day, are represented with a dash (-). The biggest value obtained in the user's mobility during a day is carried out from the building "E.T.S. de Gestión en la Edificación" and the "E.T.S. Ingeniería Informática" (4912 roamings). This is because of the buildings situation. The easiest way to access the "E.T.S. Ingeniería Informática" building is through the "E.T.S. de Gestión de la edificación" building. Furthermore, this last building is located in front of a tram stop, so it is an entry zone to this part of the university.

In Table II, it can be seen that "E.T.S. of Telecommunication" building has many roamings to other buildings. The reason is similar to the previous one, in front of this building there is also a tram stop and this building is located in the central area of the main campus. Among the "E.T.S. de Telecomunicación" and "E.T.S. de Caminos, Canales y Puertos" there are 2290 roamings in a day, this is because it is needed to cross the "E.T.S. de Telecomunicación" building to arrive to "E.T.S. de Caminos, Canales y Puertos" building. Another building that has a lot of roamings is the "E.T.S.I. Geodésica, Cartográfica y Topografía" building. In this case these roamings were caused because it is placed near the snack bar. This snack bar has wireless coverage thanks to the APs of the "E.T.S.I. Geodésica, Cartográfica y Topografía" building. We will see several movements related with this building in our studies. Lastly, among the "E.T.S.I. Caminos, Canales y Puertos" building and "E.T.S. Arquitectura" building there are 2202 roamings by day. These roamings could be due to:

a) The proximity between both buildings

b) The relationship of contents that are taught in both buildings. May be students and/or professors walk from one building to the other in order to carry out theoretical or practice classes.

C. Roaming during a month in the Vera Campus

Table III shows the roaming value carried out during a month among the buildings of the Vera Campus of the Universitat Politècnica de Valéncia. In this table, the data movements from one building to another, and vice versa, have been added. That is, we have not considered the direction of the roaming.

The maximum number of roamings in one month is carried out among the "E.T.S. de Gestión en la Edificación" building and "E.T.S. Ingeniería Informática" building. We explained why before. The number of roamings between "E.T.S. de Telecomunicación" and "E.T.S. de Caminos, Canales y Puertos" buildings was 26746. In this case roamings were due to the proximity of the buildings and because it is necessary to cross the building "E.T.S. de Telecomunicación" to arrive to "E.T.S. de Caminos, Canales y Puertos" when the people come from the tram.

There were also many user movements between "E.T.S. Arquitectura" building and the "E.T.S. de Telecomunicación" building (17704 user movements in a month).

The "E.T.S. Ingeniería del Diseño" and "E.T.S.I. Industriales" buildings have also a lot of roamings. These buildings have many users registered (see Table I). There are many roamings between these buildings due to the likeness of the studies. It seems that there are many subjects imparted by the same department, so there are professors moving between these buildings indistinctly.

"F. de Bellas Artes" building had less roamings. We think that it is because "fine arts" students do not use too much computers, laptops or mobile devices to connect to the wireless data network, as it happens with the students of the other buildings (this is a technical university).

Lastly, "E.T.S. Medio Rural y Enología", the "E.P.S. Alcoy", and "E.P.S. Gandia" have very few movements between them (there are 1350 roamings among "E.P.S. Alcoy" and "E.P.S. Gandia"). This is because these buildings belong to different campus located in different cities. There are users that one day can be in a campus and, after some hours, they are in another campus. In this case there is a hard-roaming because the user loses the connection during a large time because the user is travelling. If we take into account the buildings of the Vera Campus we observe that the most number of roamings are between the Vera Campus and the rest of campuses.

D. Roaming between Campuses

Figure 1 shows the values of the roamings carried out among the different campuses of the Universitat Politècnica de Valéncia during a month. These campuses are Escuela Politécnica Superior de Gandia (located in Gandia city), Escuela Politécnica Superior de Alcoy (located in Alcoy city), E.T.S. Medio Rural y Enología (located in one of the main avenues of Valencia City).

The number of movements in a month between the Gandia's campus and the Vera's campus are 5497. It is the highest value between campuses. There are quite a lot of movements between Gandia's campus and Vera's campus because they are relatively near (around 56 km.). There is a good public transport communication and many professors of Gandia's campus also work in Vera's campus. Moreover, a lot of lecturers of E.P.S. de Gandia have in Vera's campus their place, where they do their researches. The roamings between Alcoy's campus and Vera's campus is quite lower (1844 roamings), the reasons are very similar but there are fewer movements because in Alcoy there are less people.

TABLE II. ROAMING BETWEEN BUILDINGS IN ONE DAY.

	E. P. S. Alcoy	E.T.S Ingenieria Informática	E.T.S. Arquitectura	E.T.S. Gestion en la Edificación	E.T.S. De Ingenieria Del Diseño	E.T.S. Medio Rural Y Enologia	E.T.S.I. Agronomos	E.T.S.I. Caminos, Canales y Puertos	E.T.S.I. Telecomunicación	E.T.S.I. Geodesica, Cartografica y Top.	E.T.S.I. Industriales	E. P. S. Gandia	Facultad De Administración y Dirección de Empresas	Facultad De Bellas Artes
E. P. S. Alcoy		—	—	—	—	—	7	—	—	—	—	—	—	—
E.T.S Ingeniería Informática	3		1296	—	428	—	385	564	—	—	—	—	113	40
E.T.S. Arquitectura	—	—		—	—	—	701	—	—	—	—	—	42	—
E.T.S. Gestion en la Edificación	15	4912	986		341	—	494	568	—	—	—	—	111	195
E.T.S. Ingenieria del Diseño	6	—	249	—		—	137	200	—	—	—	—	279	27
E.T.S. Medio Rural y Enologia	—	7	12	17	4		24	11	—	—	9	—	2	4
E.T.S.I. Agronomos	—	—	—	—	—	—		—	—	—	—	—	55	—
E.T.S.I. Caminos, Canales y Puertos	2	—	2202	—	—	—	248		—	—	—	—	47	49
E.T.S.I. Telecomunicación	2	663	1379	1307	458	20	218	2270		—	507	28	100	95
E.T.S.I. Geodesica, Cartografica y Topografía	4	94	50	92	304	1	47	40	64		50	2	1047	12
E.T.S.I. Industriales	12	491	742	537	475	—	965	434	—	—		5	76	72
E. P. S. Gandia	32	16	7	20	7	—	10	24	—	—	—		4	—
Facultad Administración y Dir. de Empresas	—	—	—	—	—	—	—	—	—	—	—	—		—
Facultad Bellas Artes	—	—	86	—	—	—	52	—	—	—	—	—	10	

TABLE III. ROAMING BETWEEN BUILDINGS IN A MONTH.

	E.T.S de Inge. de Informatica	E.T.S. de Arquitectura	E.T.S. de Gestión de la Edificación	E.T.S. de Ing. del Diseño	E.T.S. del Medio Rural y Enología	E.T.S.I. de Agronomos	E.T.S.I. de Caminos, Canales y Puertos	E.T.S.I. de Telecomunicación	E.T.S.I. de Geodesica, Cartografía y Top.	E.T.S.I. de Industriales	E. P. Superior de Gandia	F. de Adm. y Dirección de Empresas	F. de Bellas Artes
E. P. S. Alcoy	67	378	389	161	2	136	67	96	163	315	1350	70	2
E.T.S de Ingenieria de Informatica		15643	62768	5806	166	7906	7344	10429	1276	6704	845	1231	3448
E.T.S. Arquitectura			13226	4163	267	8591	15180	17704	652	9314	502	670	1164
E.T.S. de Gestión de la Edificación				5535	494	7906	7531	15996	1572	8389	698	1837	2431
E.T.S. de Ingenieria del Diseño					98	1914	3304	7644	3214	7804	334	3470	480
E.T.S. del Medio Rural y Enología						636	423	365	19	184	20	78	38
E.T.S.I. Agronomos							3104	3139	487	11437	572	965	708
E.T.S.I. de Caminos, Canales y Puertos								26746	464	5811	979	557	577
E.T.S.I. de Telecomunicación									958	7785	1054	1286	1181
E.T.S.I. de Geodesica, Cartografía y Top.										767	145	11086	161
E.T.S.I. Industriales											230	1162	796
E. P. S. Gandia												99	39
F. de Administración y Dir. de Empresas													168

The number of roamings among "E.T.S. Medio Rural y Enología" and Vera's campus is 2768, but there are very few movements between "E.T.S. Medio Rural y Enología" and Gandia's campus, and between "E.T.S. Medio Rural y Enología" and Alcoy's campus.

We can see in Figure 1 that Vera's campus is the campus that receives more visits. This result is a prospective fact because Vera's campus is the main campus of our university and most of the formalities, documentation procedures, applications and administrative issues have to be made there.

Lastly, we can see that 1350 movements per month are carried out among "E.P.S. de Gandia" and "E.P.S. de Alcoy". The main reason of these movements is the existence of many professors that teach classes in both campuses so they must move between them.

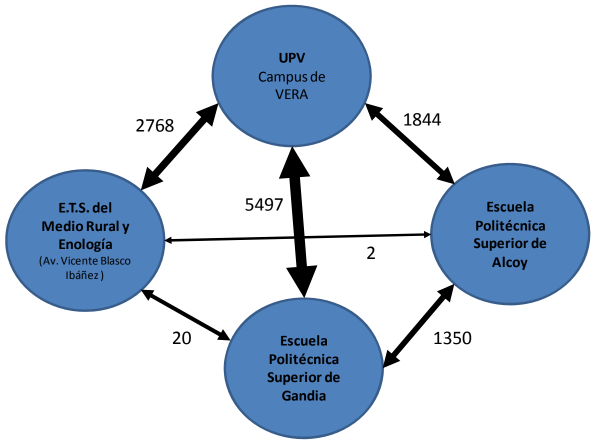

Figure 1. Roaming between Campuses

E. *People Behavior*

In this section, we will evaluate the users' movements by day in the Vera's campus. We will also analyze the number of changes carried out per user in a day.

In Figure 2, the 5 highest roaming values between buildings are shown. The situation of more mobility is given among "FI" and "GE". It has a value of 4912. In this figure, all of displacements shown have a higher value than 1834 movements/day. In this case, the movements are given among "IND"-"BIB", "DSIC"-"EI", "ARQ"-"BIB" and "CASALU"-"BIB". With these data we can obtain some information. E.g. the students of "E.T.S. Arquitectura" and "E.T.S.I. Industriales" visit the university library more times than the other students of the university. On the other hand, there are many movements among the university library building and the "Student's house" building (this building is used by the students to study, to connect to Internet and to develop any activity). This movement is due to the vicinity of buildings (see Figure 2) and many users that are in one of the buildings usually visit the other building. In Figure 3, the 10 highest roaming values are shown. In this case, we have the 5 previous movements (see Figures 2) and 5 more. These 5 new displacements are carried out among "GE"-"DSIC", "GE"-"ARQ", "FI"-"EI", "ARQ"-"ASIC" and "ARQ"-"CCP". The minimum number of roamings of all displacements seen in Figure 3 is 1483 per day. One of the buildings that had more movements is "ARQ" (E.T.S. Arquitectura). The main reason seems to be because some services are offered in this building. For example, this building has some snack bars, and there are some banks in the bottom plant. We can also find a hairdresser, bookstores, etc. and it can be found a great number of movements among this place and other buildings.

Figure 4 represents all the Vera's campus movements during one day. Almost all of buildings have users' mobility. We can state that the wireless network of our university is very robust. This network can support the mobility of all users giving the appropriate service.

Lastly, we analyzed the number of changes per person. This information is shown in Table IV.

Expression (1) is used to know the number of changes per person.

$$Changes/Person = \frac{Total\_changes\_between\_buildings}{registered\_people\_Building\_1 + registered\_people\_Building\_2} \quad (1)$$

The buildings that have the biggest number of movements per person are “E.T.S. de Gestión en la Edificación” and “F. Informática” buildings. They obtained a value of 0.797 movements per person. The movements among “IND”-“BIB” and “ARQ”-“BIB” also possess a high number of changes per person, 0.644 and 0.608 respectively.

VI. MOBILITY OF USERS INSIDE OF A BUILDING (MICRO-MOBILITY)

In the previous section we have analyzed the mobility between buildings and campuses. Now in this section we are going to study the mobility of the most mobile users from the point of view of small-scale mobility.

A. First steps in micro-mobility

In this subsection we are going to present the data from the point of view of micro-mobility. Firstly, we have selected the number of clients per day, which visit only one AP, two APs, and so on until 9 APs. This is depicted on table V.

TABLE IV. CHANGES/PERSON BETWEEN SOME BUILDINGS .

Buildings with Roaming	Registered People Building 1	Registered People Building 2	Changes	Changes/person
FI-GE	3240	2920	4912	0,797
ARQ-BIB	3858	—	2344	0,608
IND-BIB	3479	—	2239	0,644
CCP-ARQ	3145	3852	1772	0,253
FI-EI	3240	60	1744	0,528
GE-DSIC	2920	40	1705	0,576
FI-DSIC	3240	40	1484	0,452
EI-GE	60	2920	1380	0,381
TEL-ARQ	1409	3858	1347	0,256
CASALU-ARQ	—	3858	1308	0,339

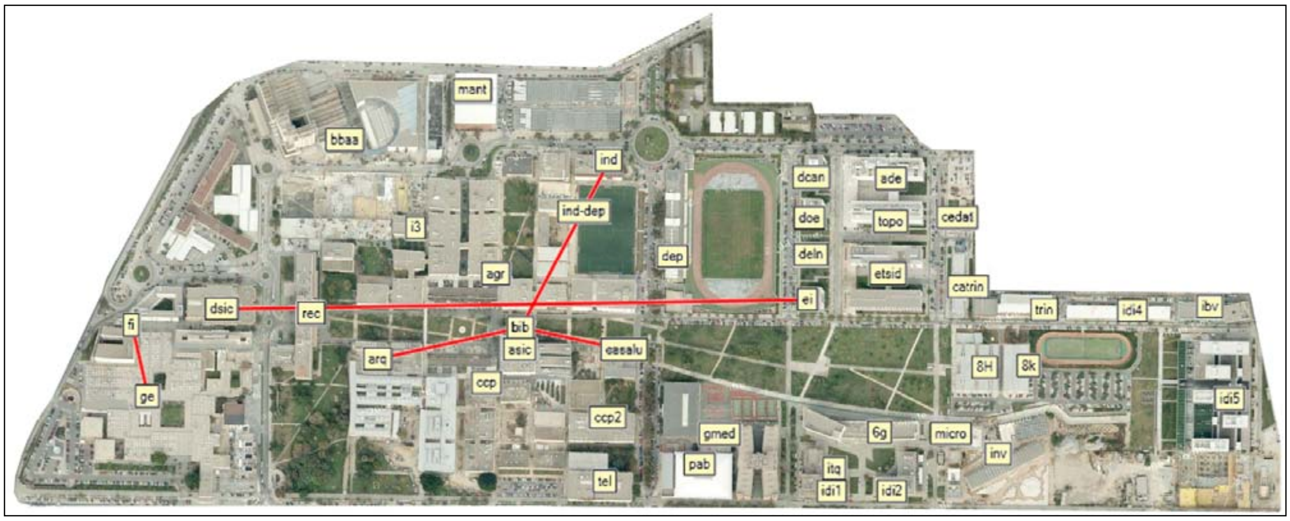

Figure 2. 5 highest roaming values in Vera’s Campus

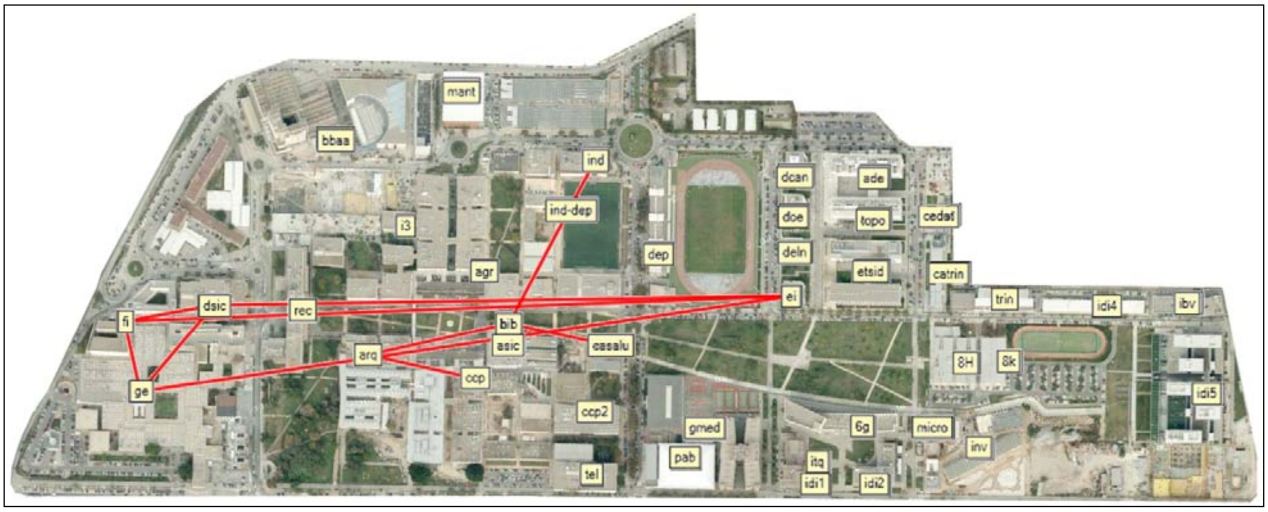

Figure 3. 10 highest roaming values in Vera’s Campus

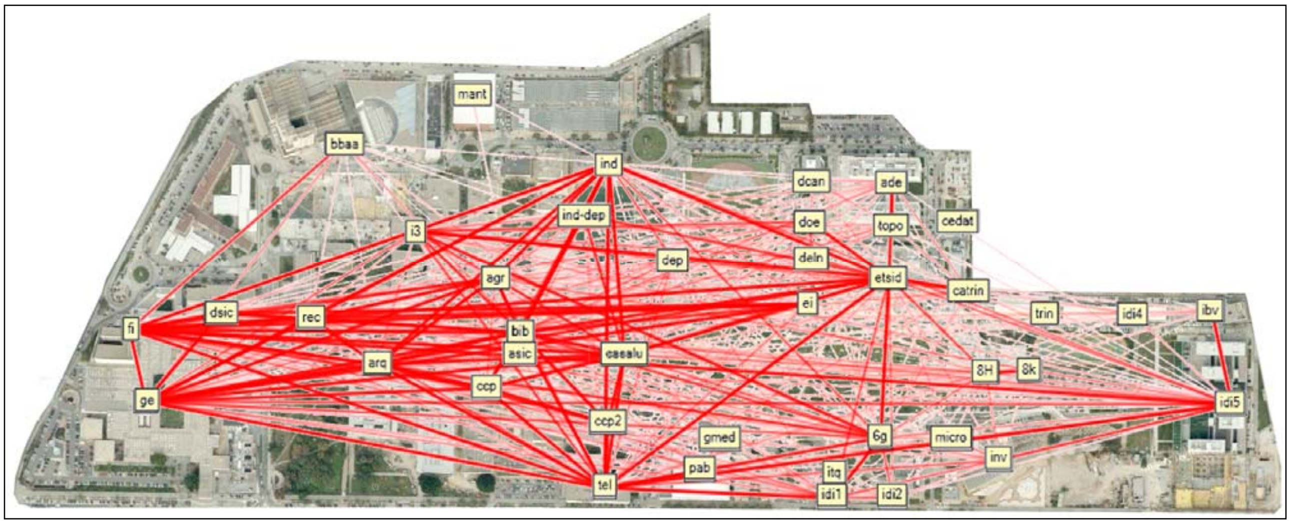

Figure 4. All roaming values in the Vera's Campus

These data were taken for a month. We assume that clients with 1 or 2 APs visited are statics because the wireless coverage in our campuses is nearly 100% so there are a lot APs to cover the maximum number of sites. Other users visit about 3 or 4 APs a day, meaning that they are limited mobile clients. From now on we will call that kind of clients as "laptop clients" because this type of users take their laptops and they go from their offices to another site to make a meeting. Finally we have the true mobile users, and we consider any user as a mobile user when a client has been detected in 5 or more than 5 different APs.

In Figure 5, it is represented the visits collected per day in each case. In this figure we can observe that all lines have the same pattern. We can extract several conclusions from this figure. First there are more static people than mobile people, because we can see that the line referenced to 1 AP visited per day is higher than others. Moreover, there are some days that break the normal pattern, this is due to these days are Sundays (on Sundays, faculties are close and only the library and the student house are open), e.g. the eighth day. Besides, between the 14^{th} and the 20^{th} day, there are few visits registered in APs, because for these days we had holiday time. As we can see, these maximum and minimum values are in all patterns, independently if we have a mobile or a static user. In mobile users these values are softer because we have fewer users.

Total numbers in this test can be viewed in the table V. In this table we shown the total visits that have only one AP, 2 AP and so on until 9 AP. Apart from that, we have calculated the percentage of these total visits and the percentage of visits when a client has visited more than *x* APs, being *x* the number of APs visited. In this table we can observer that the 58.6% of the users in our university are static. The 23.1% are laptop users and the rest are mobile users (18.3%). Although this percentage seems a bit low, in our community means that 7686 people are mobile users. So, it is important to know this data when we redesign the wireless network or when we try to implement roaming systems to improve the quality of the end-applications.

In order to analyze our collected data we need to select the correct data and the data that disturb our analysis. According to these criteria, the holiday days and Sundays we have to delete. In Figure 6 we represent a boxplot to see where the most important data are. This figure shows the maximums and minimums (start and end of lines) clients who have been associated to 1 AP, 2 AP, 3 AP, etc. In each AP, the green box represents that the most of data are between these intervals. For example, if we pay attention in the users who visit two APs, minimum value is 179 visits (it occurred the 20^{th} day), the maximum value was obtained on the 2^{nd} day and the number of visits was 1541. For this case the most of visits are between 812.5 and 1167. We can observe that the boxes are smaller according to the number of APs are higher, it is due to the number of mobile clients are lower than static or laptop clients. When we have clients, which have visited 7, 8 or 9 access points, the variability of their associations is very small compared with the static clients, it occurs for the same reason. In table V we can see that the most mobile clients (7, 8 or 9 APs visited) represent the 5.6 % of total registered users.

Finally in this subsection we want to show another figure, which represents the APs needed according to the different visits number (see Figure 7). In order to make this figure we have deleted the data, which could get worse our analysis, we have deleted the 2^{nd} day and the holiday period (14^{th} – 20^{th}, both included). In this figure we have used the average number of visits to print the line called data and then we have made a mathematical approximation with the trend line.

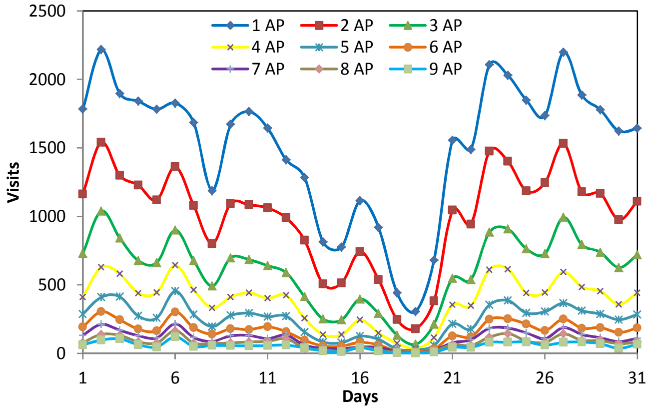

Figure 5. Visits per day for a month

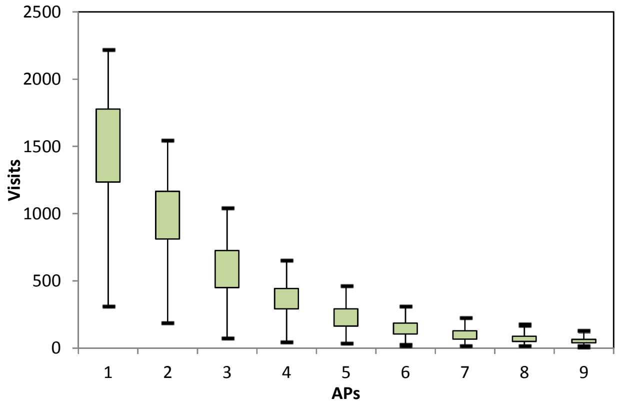

Figure 6. Boxplot of visits per AP.

TABLE V. TOTAL APS VISITED PER DAY FOR A MONTH.

APs visited per day	1 AP	2 APs	3 APs	4 APs	5 APs	6 APs	7 APs	8 APs	9 APs	> 10 APs
Total	46936	31010	18870	11900	7564	4904	3373	2393	1704	4408
Percentage	35,3%	23,3%	14,2%	8,9%	5,7%	3,7%	2,5%	1,8%	1,3%	3,3%
Total > x		64,7%	41,4%	27,2%	18,3%	12,6%	8,9%	6,4%	4,6%	3,3%

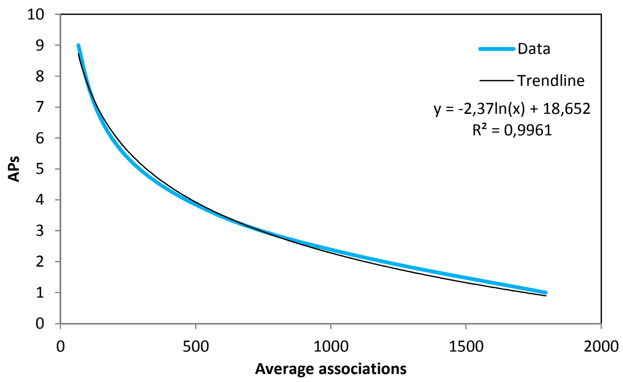

Figure 7. AP needed according to is tythe visits.

According to Figure 7, we can affirm that if we had few visits in our APs, we should configure our APs to manage mobile user correctly. However, if we had a lot of visits in our APs, we should configure our wireless network to provide the service to static users. So, the question is regarding to the number of visits, how I know if a user is mobile?

We relate the mobility of a user according to the different number of APs visited. When 1 or 2 APs are visited, we say that the user is static, but when 3 or 4 APs are visited, the user is light itinerant and when more APs visited, the user is mobile.

We have estimated relationship between the number of visits and the number of APs visited, in this scenario. This relationship is shown in expression 2. *APv* is the number of access points visited and *visits* are the different visits registered by the access point.

$$APv = -2.37\ln(visits) + 18.652 \qquad (2)$$

This expression has a R^2 equals to 0.9961. R2 means the proportion of variability in a data set that is accounted for by the statistical model. It provides a measure of how well future outcomes are likely to be defined by the model. In our case the 99.61% of data follow the model, but this model is calculated with average visits. For this reason, we have checked our real data with this model and we have obtained that the 84.48% of data follow this model. It is a good result and our model could be used for our university to make some changes in the network as we will see in the conclusions.

B. Mobile users

In this subsection we analyze the behavior of the most mobile users. In order to know who is he or she, we have defined several SQL queries (but always maintaining the anonymity of the persons). In order to have a better study, we have observed more data. In this case, the observation time period has been two months (March and April of the year 2010).

Figure 8 plots the visits that a regular user makes during 2 months. We have observed that during this time, this user does not have mobility every day, so this figure shows only the days that the user has had mobility.

According to Figure 8, we can state that the user has quite mobility, because in many cases it has had more than 10 visits per day (even up to 55 visits in one day), so it is an important value. It seems that this user works only with a mobile device and it is always connected to the wireless network, which allows us to register all the user's movements.

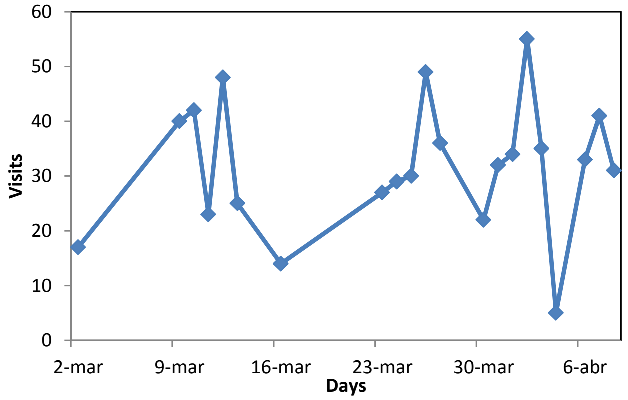

Figure 8. Visits of the most mobile user.

C. Micro-mobility in Gandia's Campus

Now, we are going to fix in a smaller place than Vera's Campus, this is Gandia's Campus. This campus is the second biggest one, if we pay attention to the number of people (according to Table I, 2039 people are registered).

We can see the campus in Figure 9. This figure represents several buildings; each one has its name according to a letter. In this map, we have located the access points (black points) approximately in the correct place. We say approximately because all buildings have several floors and in order to make a good design, sometimes the APs are situated in other places because we want more coverage or less interference.

Moreover, the name of each AP in our university helps us to know where it is more or less located. The names follow a structure. We are going to explain it with an example.

The access point called *ac1-gnd1a0e.net.upv.es* has the following explanation. First three letters *"ac1"* is the model of the access point used. Then, the following three ones, in this case *"gnd1"*, is the location. *"gnd1"* is Gandia, but this part of the name is the same for all names in Table IV. Then, there is the name of building and the floor, in this case *"a0"* means building A and floor 0. Next, there is the orientation: north = n, south = s, west = o and east = e. In the example we have an access point located in the east, *"e"*. Finally, we have *"net.upv.es"* means that this device belongs to UPV.

In order to analyze the movement of a user, we have selected the most mobile user of Gandia's Campus. We are going to see his movement using the Table VI. It shows us the access point name, where the user has visited, the day and the time.

In this case we can see that this user has quite mobility in few hours. The mobility of this user starts at 11:00. First he connects to *"ac1-gnd.1a0c.net.upv.es"*, so he is located on building A, in floor 0 and on the AP of the center. He moves to the east (*"ac1-gnd.1a0e.net.upv.es"*) on the same floor and then he goes up to the first floor. He stays there during an hour. Then, the user does the similar movement steps. At 13:34 he stays at the AP of the center of building A, in floor 0. Then, he goes to the east direction and to the first floor. At 14:42 he changes to the D building, firstly to the ground floor, and then to the first floor. Next, he goes to the E building, and he goes up to 6th floor (*"ac1-gnd1e6c.net.upv.es"*). Finally, he goes to the outside of the buildings (*"ac3-extgnd1.net.upv.es"*) until 16:05.

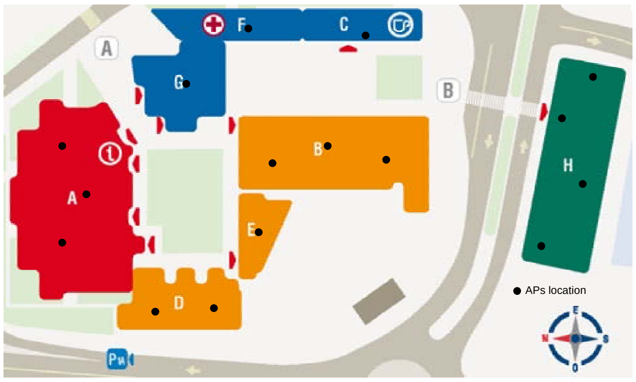

Figure 9. Gandia's Campus.

TABLE VI. MOBILITY IN GANDIA'S CAMPUS.

MAC address	Month	Day	Hour	AP name
000d.720c.fc37	Mar	5	11	ac1-gnd1a0c.net.upv.es
000d.720c.fc37	Mar	5	11	ac1-gnd1a0e.net.upv.es
000d.720c.fc37	Mar	5	11	ac1-gnd1a1e.net.upv.es
000d.720c.fc37	Mar	5	12	ac1-gnd1a0c.net.upv.es
000d.720c.fc37	Mar	5	13	ac1-gnd1a0c.net.upv.es
000d.720c.fc37	Mar	5	13	ac1-gnd1a1e.net.upv.es
000d.720c.fc37	Mar	5	14	ac1-gnd1d0c.net.upv.es
000d.720c.fc37	Mar	5	14	ac1-gnd1d1s.net.upv.es
000d.720c.fc37	Mar	5	14	ac1-gnd1e6c.net.upv.es
000d.720c.fc37	Mar	5	14	ac3-extgnd1.net.upv.es
000d.720c.fc37	Mar	5	16	ac1-gnd1a1c.net.upv.es
000d.720c.fc37	Mar	5	16	ac1-gnd1a1e.net.upv.es
000d.720c.fc37	Mar	5	16	ac1-gnd1a1o.net.upv.es
000d.720c.fc37	Mar	5	16	ac1-gnd1c0c.net.upv.es
000d.720c.fc37	Mar	5	16	ac1-gnd1d2c.net.upv.es
000d.720c.fc37	Mar	5	16	ac1-gnd1e1c.net.upv.es
000d.720c.fc37	Mar	5	16	ac1-gnd1e5c.net.upv.es
000d.720c.fc37	Mar	5	16	ac1-gnd1e7c.net.upv.es
000d.720c.fc37	Mar	5	16	ac1-gnd1f1c.net.upv.es
000d.720c.fc37	Mar	5	16	ac1-gnd1g2se.net.upv.es
000d.720c.fc37	Mar	5	16	ac3-extgnd3.net.upv.es
000d.720c.fc37	Mar	5	17	ac1-gnd1d1n.net.upv.es
000d.720c.fc37	Mar	5	17	ac1-gnd1e1c.net.upv.es
000d.720c.fc37	Mar	5	17	ac1-gnd1e2c.net.upv.es
000d.720c.fc37	Mar	5	17	ac1-gnd1e3c.net.upv.es
000d.720c.fc37	Mar	5	17	ac1-gnd1e6c.net.upv.es

At 4 p.m he starts to move a lot. He is on the first floor of building A, then, he moved to building C. When he finished his activities on this building he went to building D, and then, he went to building E, staying in the first floor, the 5th floor and, finally, the 7th floor. Next, he went to the 1st floor of building F. Then he went to the 2nd floor of building G and, finally, he moved to the outdoor zone. Finally, at 5 p.m. he went from the 1st floor of building D to building E. In this building he moved from the 2nd, to the 3rd and, finally to the 6th floor. And, then, he finished his movements.

According to these movements we could indicate what kind of person has this behavior. In this case, we think that he could be a language lecturer because, first, he was on building A, where the classrooms are placed, maybe he is teaching his lessons. Then, he went to his office (language offices are on building E). From 14:42 to 16:05 he went to take his lunch outside of the university. Then, he went to building A. May be he enters to the university through this building. He went to his office again and, then, he went to building F (another place where are language offices) to see a colleague and they went to the bar (building C). Finally he came back to his office. With this type of micro-mobility we can observe the people behavior only by using wireless networks. When the same movements are done by many people at the same time, we can predict the needed resources for a period of time in a specific place. May be, the network will require more devices in an specific part of the network because of the number of connections during a limited period of time one day in a week.

VII. Conclusion and Future Work

In this paper, we presented a user mobility study based on the roaming of the MACs in the wireless network of the Universitat Politècnica of València. We made two types of studies. First we have analyzed the macro-mobility. In this case, the mobility between buildings and campuses has been studied. Second, we studied the micro-mobility that let us know the mobility inside buildings.

Using the measured data we can analyze the behavior of students and professors in the campus. This study let us build reallocation bandwidth scenarios to increase the comfort of the end user, i.e., if we note that a set of users go far to an area, we could determine in detail where will they go. May be this information could be used to reallocate services and departments in the campus by changing their place or putting a branch near the appropriate place.

Besides, we could see that making a detailed WLAN study (micro-mobility), and knowing behavior of some people allow us to know the type of person that is walking through the areas. This type of study could let us know where we should place the network printers, the coffee and drinks machines, and some internal services.

We have also shown that we can obtain some information about the user just studying his mobility profile. This kind of information could be used also for advertising services, direct marketing and similar tasks.

Finally, this analysis will be the basis for our future work on a dynamic management and control system of the wireless network. According to the user mobility, the system will be able to give more bandwidth in those areas where more users are, and the roaming system will be more efficient. Even we are thinking on talking with the transport services to let them know which is the mobility between our campuses in order to provide an adequate transport service.

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