Evaluation of the Wireless Network used by a Tour Guide in a Cultural Environment

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Abstract—**Wireless tour guides are mobile applications running on a PDA that are very popular among cultural environments, such as museums and art exhibitions. The Human-Computer Interaction quality derived from the use of these guides heavily depends on the wireless network used to access the information of the artefacts in the cultural environment. This work presents a procedure to evaluate the Wi-Fi network performance used by a tour guide system. The procedure is applied to a real museum in Spain. The procedure is based on a set of observation and measurements performed in measurement points distributed across the cultural environment. It also presents how to analyse the coverage of the wireless network, the set of environmental factors that may degrade the performance of the network and the effectiveness of the access point selection algorithm used by the mobile device. As result of the evaluation, we have identified a set of weak points in the network development. However, they were not relevant enough to alter the actual network deployment.**

Wi-Fi;Human-Computer Interaction; Mobile applications

I. INTRODUCTION

Museum guides have evolved through the time. Traditional approaches, such as text panels next to art pieces and triptychs, have serious limitations. For instance, the physical space that is available to support multi-language information. Besides, the maintenance costs on this media are high due to information reprinting in time-limited exhibitions.

In order to solve these problems, alternatives such as audio guides, supported by cassette players or solid memory devices, or radio frequency technologies emerged providing visitors with individual access to information. Main disadvantage of these approaches is the limitation to provide audio information only.

Although Web technologies offered new opportunities to open up the walls of the museum to the world [1], the information was not offered in-situ.

Thus, the Personal Digital Assistant (PDA) emerged as a powerful tool to provide multimedia information in-situ, providing applications that served as multimedia guides for cultural environments visitors. A comparative evaluation of different platforms for augmenting museums and art galleries where the PDA proved to be a successful information provider for visitors is presented in [2]. Additionally, according to [3], the PDA has also been accepted as a good approach to face this problem.

Although there are tour guides for indoor and outdoor environments, such as the exposed in [4], we will focus on guides for indoor environments.

The infrastructure to develop tour guides for indoor environments varies according to how the information is retrieved.

On the one hand, the standalone approach proposes the information retrieval from the PDA device memory [5, 6]. On the other hand, the client-server approach proposes storing information on a central server and the retrieval is achieved from the clients (PDAs) through a wireless network connection [7].

The standalone approach has some advantages such as: (a) the lack of networking infrastructure, and (b) the server storing the information to be exposed to visitors. However, the client-server approach has also some valuable advantages compared to the standalone approach. In a client-server approach, the cultural environment information is centralized; therefore when it changes, it is automatically propagated to the clients. Besides, the client-server does not restrict the use of the guide to those devices that are provided by the cultural environment because it can be easily deployed on visitor devices (it only requires a tiny the client application to be downloaded). Under this scenario, the communication network becomes a key factor of the tour guide application because from the human-computer interaction perspective, the user experience depends on the capabilities of the wireless network to retrieve multimedia information.

This paper proposes an evaluation procedure for wireless communication networks employed to deliver information from the tour guide content server to the tour guide clients within the cultural environment.

The evaluation procedure is performed on a tour guide deployed in a real museum the Cutlery Museum of Albacete (MCA) in Albacete, Spain. The goal of the system is to provide visitors with multimedia information about the knives exposed in the building through a PDA device running the tour guide application.

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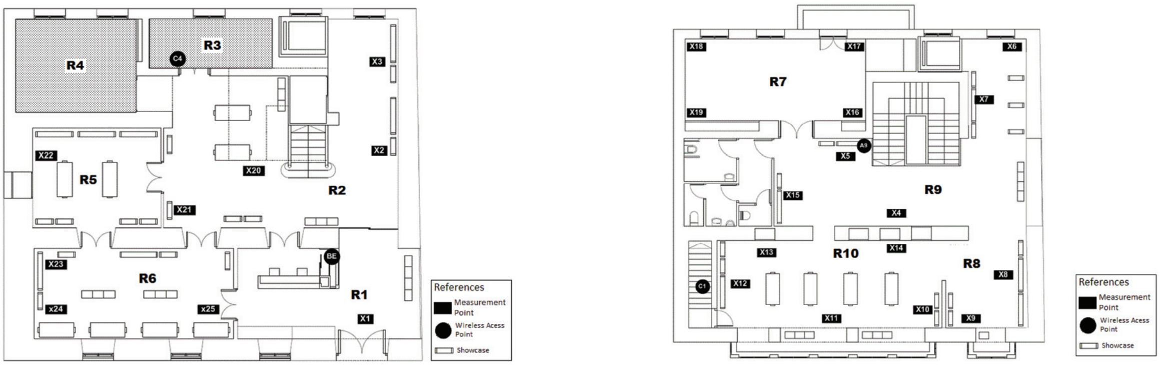

(a) (b)

Figure 1. The physical environment: (a) the ground floor (b) the first floor.

The evaluation procedure is explained as follows. In Section II, we expose how this work is related to other works, and where the evaluation procedure can be applied. In Section III, we describe the museum physical environment. Section IV presents the software and hardware architectures of the system. In Section V, we expose the measurement process and results. In Section VI, we analyse the measurements, and finally, in Section VII, we expose the conclusions and future work.

II. RELATED WORK

The evaluation of the wireless network is close related to the environment in which it is deployed. In this case, we expose an indoor environment represented by a cultural environment in which a wireless guide is deployed.

As we have mentioned in Section I, the wireless network that was evaluated was the Cutlery Museum of Albacete (MCA) in Albacete, Spain [7].

However, it is not the only wireless guide for cultural environments. There are some other interesting approaches that exploit this technology; for instance, mi-Guide [8] or the location aware system exposed in [9].

Thus, this paper proposes a guideline that can be used to evaluate the deployment of wireless networks following a defined procedure that takes into account the physical environment, the measurement process and the data analysis.

III. THE PHYSICAL ENVIRONMENT

The first step of the evaluation procedure is the analysis of the physical environment.

In the MCA, the physical environment where the system was deployed is defined by a two floor building. The ground floor and the first floor plans are depicted in Fig. 1 (a) and Fig. 1 (b).

The surface of each floor is about 200 m^2, external walls are 40 cm width, internal walls are about 25 cm width and the floor is tiled.

Floor rooms are identified by the "R" prefix. Rooms R1 to R6 belong to the ground floor, and rooms R7 to R11 belong to the first floor. The walls of the rooms are bare, except for R7 (in the first floor) that has wood-panelled walls.

Rooms also contain showcases where pieces are exposed. They are all wooden-made, but those that are in R10 that are made of stainless steel.

The Fig. 1 (a) and the Fig. 1 (b) show the distribution of showcases, wireless access points (C1, C4, A9 and B3) and measurement points (X1 - X25) through the building.

Note that the ground floor is connected to the first floor by a stainless steel elevator and a marble stair.

IV. THE WIRELESS TOUR GUIDE SYSTEM

Before introducing the measurement process, we expose in this section the hardware and software architecture to the system. This information is relevant to the evaluation process in order to specify the type of systems we are dealing with.

A. System architecture

The system is based on the traditional client-server architecture depicted in Fig. 2.

The server side of the application is composed by the Web server and the Database server. Each server is defined as a two-node cluster to improve system reliability.

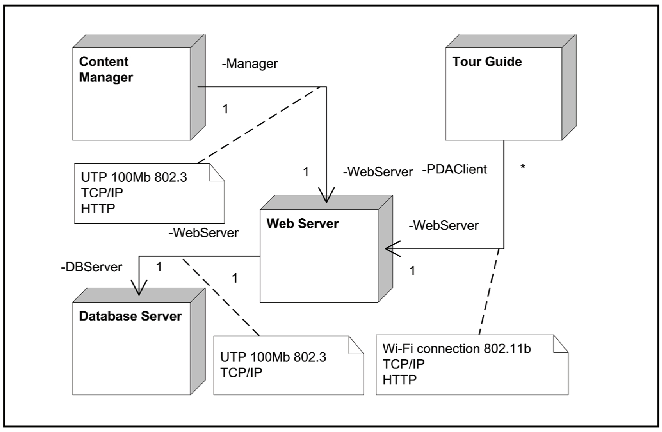

Figure 2. The wireless tour guide architecture

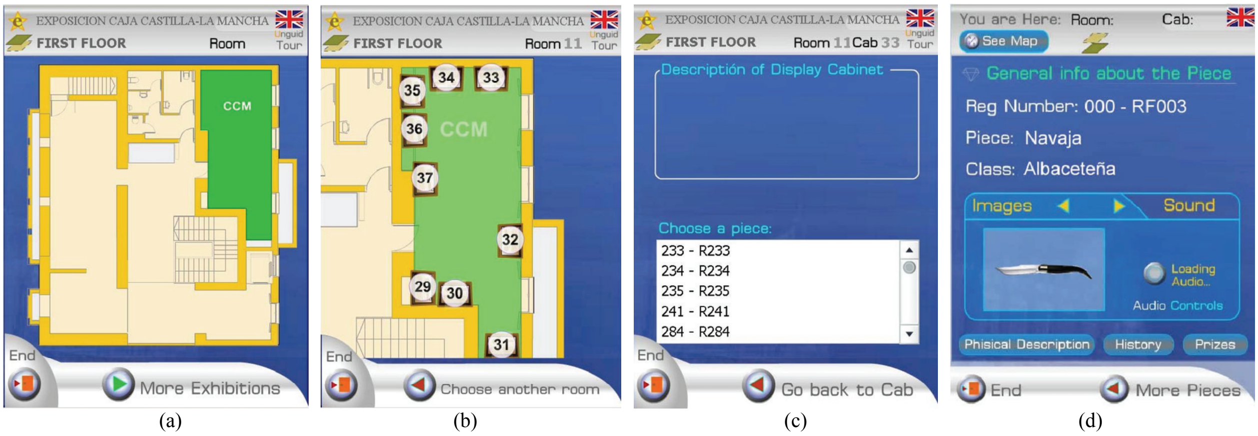

Figure 3. The client user interface (UI): (a) the floor UI (b) the room UI (c) the showcase UI (d) the piece UI.

Server machines are equipped with Pentium IV 2GHz processors with 512 MB of RAM Memory and two 100 Mbps Ethernet interfaces.

One of them is used for data synchronization between cluster nodes, and the other one is used to connect the cluster to the information system.

While the communication between database and Web servers is wired with UTP cable for 100Mb, the communication between the Web server and mobile clients is conducted by a wireless network (802.11b). Transport and communication protocols are TCP/IP in both cases.

In order to cover the whole building, we have installed five wireless access points that supports 802.11b at 2.4 GHz. Besides, to reduce the network traffic and the processing overhead in the PDA client, no encryption was enabled in the system.

The client side of the application is composed by two types of clients: the Content Manager and the Tour Guide. The Content Manager is designed as a "What You See Is What You Get" (WYSWYG) application to manage the information of to be provided to visitors. On the other hand, the Tour Guide is designed as a PDA based application that runs on a PDA.

Each PDA is equipped with a 400 MHz processor, 64 Mb of SDRAM, 64 Mb of ROM flash memory, the QVGA TFT colour screen is 3.5 inches long and has a 320 x 240 resolution on 65,536 colours. Communication protocol is limited to 802.11b.

B. *The Client Application*

This section exposes the client application to provide readers with a conceptual idea of the wireless network load.

A full description of the application is exposed in [7] and a usability evaluation following the CIF (Common Industry Format for Usability Reports) standard defined by the ISO/IEC DTR 9126-4 is presented in [10].

The Adobe Flash technology was used to provide visitors with a high quality user interface. This interface provides visitors with the ability to explore the museum in several ways: (a) guided tour, (b) recommended routes, (c) through the finder and (d) unguided tour.

Independently of the museum exploration mode, the application provides information of floors, rooms, showcases and pieces. The Fig. 3 shows tour guide user interface.

All screens are stored locally by the device. However, the content showcase and piece related resource are retrieved from the Web server. The key screen, from the network information load point of view is the piece resource viewer. Through this interface the user is able to retrieve text, images, audio and video information.

C. *The Characteristics of theInformation*

The image file format used by the application resurces is JPG, the resolution is 800 px x 600 px and the file size varies from 5.72 KB up to 81.1KB (avg. 43.41 KB).

The audio file format used is MP3 at 22 KHz and 32 Kbps of bit rate; file size varies from 129 KB up to 370 KB (avg. 249.5 KB). The video video file format used is WMV, the video resolution is 352 x 288 at 368 kbps; the video and audio codec are WMV3 and two channel WMA2 at 22Khz and 32 kbps of bit rate respectively; file size is about 5 Mb.

V. THE MEASUREMENT PROCEDURE

Once, we have analysed the environment and system characteristics, we proceed with the measurement procedure. Thus, this section exposes the measurement procedure that was employed to carry out the evaluation of the MCA wireless network to be used as a guide for further procedures.

The software employed was the PDA's default software to show access point information. It provides the signal strength (S), the signal noise (N) and the S/N ratio for each access point that is at range. It also provides the access point the device is connected to.

The measurement process was carried out in two phases achieving two independent measurements following the same route. The route is defined as a sequence of points where the measurement is performed. The order of the sequence is defined by the order of the X nodes (see Fig. 1 and Fig. 2). Measurement results are exposed in Table I and Table II.

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TABLE I. AVERANGE ACCESS POINT COVERAGE

M. Point	C4		A9		B3		C1	
	S[a]	*N*[a]	*S*[a]	*N*[a]	*S*[a]	*N*[a]	*S*[a]	*N*[a]
X1	-69	-93	-76	-92	-50	-88	-77	-92
X2	-69	-91	-56	-92	-61	-91	-84	-93
X3	-76	-93	-60	-90	-75	-90	-83	-91
X4	-80	-92	-46	-92	-69	-91	-53	-92
X5	-74	-92	-41	-91	-80	-91	-59	-92
X6	-88	-92	-60	-92	-79	-91	-70	-90
X7	-78	-92	-59	-92	-76	-88	-65	-92
X8	-89	-93	-50	-91	-62	-91	-55	-93
X9	-87	-91	-51	-92	-61	-91	-58	-92
X10	-86	-92	-56	-92	-62	-92	-53	-93
X11	-90	-92	-58	-92	-67	-91	-51	-91
X12	-88	-92	-53	-91	-70	-91	-44	-92
X13	0	0	-57	-88	-72	-91	-52	-90
X14	-85	-92	-50	-92	-63	-91	-53	-91
X16	-79	-91	-55	-90	-82	-91	-68	-91
X17	-75	-92	-56	-91	-86	-90	-72	-93
X18	-82	-93	-61	-88	-85	-87	-74	-92
X19	-78	-91	-63	-90	-88	-91	-74	-92
X20	-56	-92	-61	-91	-68	-92	-80	-92
X21	-64	-92	-56	-89	-77	-90	-84	-92
X22	-69	-92	-59	-92	-78	-92	-82	-92
X23	-78	-92	-83	-93	-53	-91	-73	-91
X24	-80	-92	-85	-90	-62	-92	-72	-91
X25	-84	-92	-76	-91	-48	-91	-78	-90

a. dB unit used

TABLE II. MOBILE DEVICE CONNECTION QUALITY

M. Point	Phase I			Phase II			Best
	A.P.	*S*[a]	*N*[a]	*A.P.*	*S*[a]	*N*[a]	*S / N*[b]
X1	BE	-50	-88	BE	-50	-88	BE
X2	C4	-69	-91	BE	-61	-91	A9
X3	A9	-60	-0	A9	-60	-90	A9
X4	A9	-46	-92	A9	-46	-92	A9
X5	A9	-41	-91	C1	-59	-92	A9
X6	A9	-60	-92	C1	-70	-90	A9
X7	A9	-59	-92	C1	-65	-92	A9
X8	A9	-50	-91	C1	-55	-93	A9
X9	A9	-51	-9	C1	-58	-92	A9
X10	A9	-56	-92	C1	-53	-93	C1
X11	A9	-58	-92	C1	-51	-91	C1
X12	A9	-53	-91	C1	-44	-92	C1
X13	A9	-57	-88	C1	-52	-90	C1
X14	A9	-50	-92	C1	-53	-91	A9
X16	A9	-55	-90	C1	-68	-91	A9
X17	A9	-56	-91	C1	-72	-93	A9
X18	A9	-61	-88	C1	-74	-92	A9
X19	A9	-63	-90	A9	-63	-90	A9
X20	A9	-61	-91	A9	-61	-91	C4
X21	A9	-56	-89	A9	-56	-89	A9
X22	A9	-59	-92	A9	-59	-92	A9
X23	A9	-83	-93	BE	-53	-91	BE
X24	A9	-58	-90	BE	-62	-92	BE
X25	A9	-76	-91	BE	-48	-91	BE

a. dB unit used, b. dBW unit used

On the one hand, Table I shows the average access point coverage defined by the signal and noise strength received by the mobile device from all access points. On the other hand, Table II shows mobile device connection quality exposing the access point selected by the mobile device on each phase and the best option according to the measurements on Table I.

VI. THE MEASUREMENT ANALYSIS

This section analyses the measurements collected from Section V They are used to perform the analysis of the following set of features of the wireless network: (a) the signal coverage in the building, (b) the algorithm employed to choose an access point and (c) the environmental factors that affect the signal propagation.

A. The Signal Coverage in the Building

In order to evaluate the signal coverage in the building we use the signal-noise ratio as the reference parameter.

Thus, the equation (1) defines the f_r function that takes a measurement point x_i and an access point p_j as parameters to return the signal/noise ratio from p_j at x_i. The M constant defines the total amount of measurement points and the A constant defines the total amount of access points.

$$f_r\,(x_i, p_j),\ i \in [1\ldots M] \wedge j \in [1\ldots A] \qquad (1)$$

The R_{MAX} and R_{MIN} values, exposed by the equations defined in (2), represent the maximum and the minimum signal/noise ratio that have been measured during both measurement phases.

$$R_{MAX} = f_r (x_k, p_l),\ \forall\ i, j\ (f_r (x_k, p_l) \geq f_r (x_i, p_j))$$

$$R_{MIN} = f_r (x_k, p_l),\ \forall\ i, j\ (f_r (x_k, p_l) \leq f_r (x_i, p_j)) \quad (2)$$

$$\forall\ i, k \in [1\ldots M] \wedge \forall\ j, l \in [1\ldots A]$$

Finally, (3) defines $g_r (f_r (x_i, p_j))$ that returns 1 if p_j covers x_i, or 0 otherwise.

$$r = f_r (x_i, p_j);\ RLIM = (R_{MAX} - R_{MIN})/2$$

$$g_r (r) = 1 \Leftrightarrow r \in [R_{LIM}\ldots R_{MAX}] \quad (3)$$

$$g_r (r) = 0 \Leftrightarrow r \notin [R_{LIM}\ldots R_{MAX}]$$

The application of the equations on measurement results is represented by the Fig. 4 (a). It shows the signal/noise ratio from the "best" access point on each measurement point. It also depicts the R_{MAX}, R_{MIN} and the R_{LIM} values. The main reason for being below R_{LIM} may be related to: (a) interference because of environmental conditions or (b) the algorithm used to select the access point the device connects to. To solve this question, we analyse these parameters in next subsections.

From Fig. 4 (a), we may also conclude that although in both phases the coverage was not complete, the wireless network is able to fulfil this requirement because if the best access points would have been selected the 100 % of measurements points would have been covered.

B. Environmental factors

This section analyses the environmental factors, such as interference generators, that may degrade the link quality. The first parameter to analyse is the noise as reference parameter.

The problem will be discussed at two levels. On the one hand, the first level studies the environmental noise in the building. On the other hand, the second level studies the set of particular situations that we have revealed on previous section.

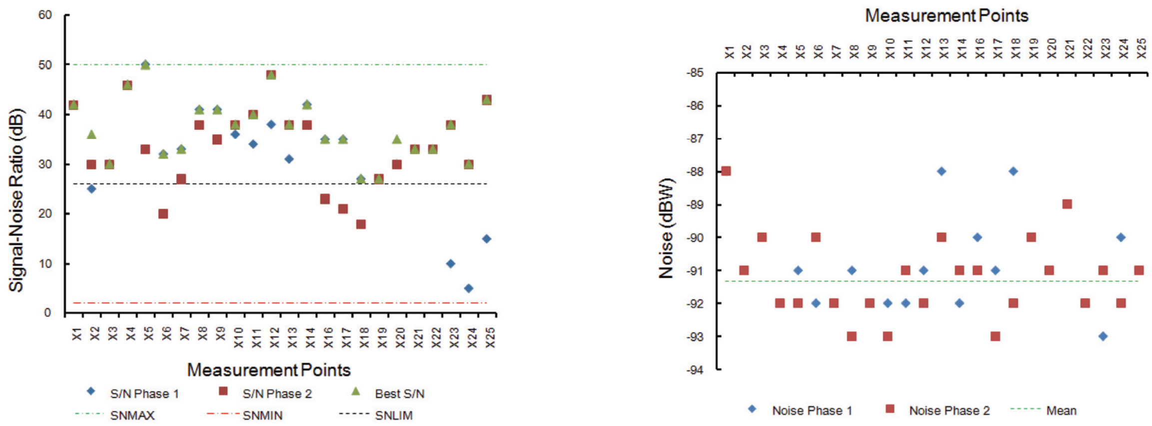
1) The Environmental Noise. In order to study the environmental noise, we base our analysis in the noise level through the building. These levels are depicted in Fig. 4 (b). Thus, the equation (4) defines the function that takes a measurement point x_i and an access point p_j as parameters to return the signal noise at x_i from the p_j. Once noise function was defined, we apply (5) to obtain the X_m= -91.32 dB and the S_x = 1.19 dB. These values show that noise levels are stable.

$$f_n (x_i, p_j),\ i \in [1\ldots M] \wedge j \in [1\ldots A] \quad (4)$$

$$X_m = (\Sigma\ f_n (x_i, p_j))/N \wedge S_x = (\Sigma\ f_n (x_i, p_j)) - X_m)^2/N;\ N=i\cdot j \quad (5)$$

Some Particular situations. Once we have analysed the environment as a whole, we continue with the analysis on problematic measurement points. First, we will analyse X2, X23, X24 and X25 from the first phase. Focusing on X2 in Fig. 1 (a) we can see that it is in the middle of two access points (C4 and BE). The most suitable is BE (see Table II). However, the C4 was chosen, even when BE was previously chosen (X1). The most reasonable explanation is the visitor orientation, coming from X1 the device may have pointed to C4 instead of BE. However, there is an argument to be discussed before closing this case. The question is related to Phase II access point selection (BE) for the same measurement point. The explanation is related to the access point selection algorithm that according to our observations follows this procedure: an access point is selected only if no access point was selected or the connection to actual access point is lost. Thus, on the one hand, in the first phase the connection with BE was lost while the visitor was pointing to C4. On the other hand, in the second phase, the connection was not lost, so no selection was made at all. The group composed by X23, X24 and X25 measurement points is attached to A9 instead of BE (C1 is discarded because these measurement points are in the ground floor and C1 is between the ceiling and the roof at first floor). In contrast to the previous case, it seems not to be the orientation of the visitor that affects the selection of the optimal access point (BE). Instead, it may be related to the access point selection algorithm described on previous paragraph. Once first phase analysis was performed, we analyse the X6, X16, X17 and X18 measurement points of second phase. The measurement point X6 is affected by the elevator that is made up stainless steel. The elevator was up when the measurement was taken, fading the signal. Another factor that has affected X6 is the change of the access point used by the mobile device from A9 to C4. It should have been provoked by the way up from ground floor to first floor through the stairs. Finally, another consequence of the change of access point mobile device from A9 to C4 is the low measurement at X16, X17 and X18.

2) The Access Point Selection Algorithm. From the analysis performed on both phase measurements, we have identified the following problems: (a) visitor orientation, (b) physical interference (i.e. elevator) and (c) the access point selection algorithm (change of access point connection). It is really difficult to control the first two problems, because they are not directly related to hardware or software. However, the access point selection algorithm deserves an extra analysis to propose future improvements on it. The results of the analisys expose that on the first phase, the 54 % of the access point selected by the device is coincident to the best possible. On the second phase of measurements, the 62 % of the access point selected by the device is coincident to the best possible. It proves that the access point selection algorithm should be improved in order to leverage the wireless network performance.



(a) (b)

Figure 4. Example of a TWO-COLUMN figure caption: (a) this is the format for referencing parts of a figure.

According to the study of building coverage we have performed, a new algorithm may leverage the signal-noise ratio to reach an optimal 100 %. Therefore, the performance may reach an average improvement of 41.67 %.

VII. CONCLUSIONS AND FUTURE WORK

This article proposes a procedure to evaluate the capabilities of wireless networks used by tour guides in cultural environments. It also applies the procedure to a real product deployed at the MCA in Albacete, Spain. It starts evaluating the signal coverage in the building and the environmental interference. As result of the analysis of these two parameters, the mobile device access point selection algorithm is evaluated conducting to the conclusion that an average improvement of 41.67 % may be achieved in the access point selection if the selection algorithm properly modified.

The future work is focused on three main research lines. The first one is related to how to improve the algorithm. We are actually exploring different ways to do it that goes from pooling to the application of prediction algorithms. On the second research line we are trying to use new mobile device features such as accelerometers and gyroscopes that could be used to acquire information from visitor movements. And finally, we are doing some research on how new technologies affect the wireless network capabilities. An example of new technology applied to this field is the use of RFID technology in both variants: passive and active, as presented in [11].

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