Mobile Service for Adaptive Museum Visits in Wireless-Optical Networks

Jean-Michel DOUIN, Olivier LEFRANCOIS, Stéphane ROVEDAKIS et Anne WEI

Laboratoire CEDRIC
CNAM (Conservatoire National des Arts et Métiers)
292 rue Saint-Martin, 75003 Paris, France. jean-michel.douin@cnam.fr

Abstract— **The emergence of new technologies make possible the design of new mobile services which are better suitable for cultural and industrial needs. In the context of a museum tour, mobile services allow visitors to obtain rapidly all the information useful for their visit. In this article, we present a mobile service in a wireless-optical network to provide an interactive tour, that is visitor guidance in the museum and multimedia contents on artworks of interest. The considered network architecture is composed of a wireless and an optical part which offer a high throughput (at most several gigabits per second). The proposed service is built for Android smartphone equipped with a Bluetooth card (for indoor localization) and the mDNS (Network Service Discovery for Android) technology (to advertise and share contents with other visitors in a mobile-to-mobile ad-hoc network). In the end of the paper, we give some performance analysis of the proposed mobile service in real situations.**

Keywords - Mobile service, interactive tour, wireless network, mobile-to-mobile connection, Android development.

I. INTRODUCTION

Many visitors prepare their visit of a museum before the real visit on site, to take advantage of their tour. However, this preparation takes a lot of time. Nowadays, the visitors need personalized and interactive tours to save time and to have a better experience. The emergence of new technologies such as smartphones and wireless networks enable to build new mobile services.

Today, an interactive museum tour could be distinguished into two classes: *real* and *virtual* visit [1-3]. The virtual tour consists to simulate the museum visit, often in 360 degrees. The image representing the visited museum evolves dynamically, following visitor's requests. A real tour can be characterized with or without augmented reality. In our case, we consider real museum tours with dynamic paths (tours) computed by a mobile service. The mobile service can propose a path to the next artwork of the tour by taking into accounts the visitor's location and its interest.

Recall that tour information is often indicated on walls of rooms in the museum or on document papers distributed at the beginning of the visit. However, we observe that some visitors do not necessarily follow the proposed tour for various reasons: 1) the visitor wants to admire an artwork that is not included in the tour; 2) the visitor has time constraints; 3) some visitors (e.g., handicapped persons) need a special tour. Consequently, it is necessary to define personalized tours. Our mobile service provides a dynamic and personalized tours following visitor's interest. This means that given a set of selected artworks that fit visitor's interest, the proposed service computes the best path using visitor's current position. Moreover, throughout its visit, the visitor can download and display a description of every artwork, thanks to our application. Additional contents can be obtained, e.g., videos or scanned images of historical documents.

This mobile application relies on an infrastructure network guaranteeing a high throughput providing access to audios and high quality videos. This infrastructure necessarily combines different network technologies to achieve high data transfer rates, while taking into account the mobility of visitors in the museum. To respect these constraints, the chosen infrastructure consists of wireless-optical communications based on the new WiFi standard IEEE 802.11ac to transfer all the information from the museum server.

When a lot of visitors are simultaneously connected to the museum server, this one may be out of service. To this end, our mobile service provides a wireless direct connection without sending request to the server (mobile to mobile ad-hoc network). These wireless connections are realised based on recent functionalities available on last versions of Android.

The main contribution of this paper is to offer assistance to visitors of a museum using the communication capabilities and localization of smartphones. Assistance uses the Nearest Neighbor algorithm, communication is wireless mobile/server and mobile/mobile (mDNS-SD), the location is defined by the presence of NFC and Bluetooth tags. The proposal is complemented by measures in terms of bandwidth on the museum site were made.

The rest of this paper is organized as follows. The next section presents the characteristics of the considered networks (infrastructure and ad-hoc). Section III describes the environment modeling and the methodology for computing the tour offered by the application to the visitor. The details of the software architecture, the Human-Machine interface and implementation considerations of the mobile service are described in Section IV. Measures in real situations are presented in Section V. Finally, we conclude our study and give some perspectives.

II. NETWORK INFRASTRUCTURE

The system considered in our project consists of two main parts: a network infrastructure with wireless and optical technologies, and a mobile to mobile ad-hoc network. As described previously, the objective of this first infrastructure is to reach a high throughput to enable the transmission of some multimedia contents with high quality, for example HD videos in streaming. For the wireless communications, several new technologies are in competition. On one hand, we can notice the WiGig/WiFi standard which offers throughput up to 7GB/s and UWB (Ultra WideBand) provides the throughput up to 480 Mb/s [4-5]. On the other hand, the optical communications evolve also very quickly since last decade. The maximum flow can reach up to 400 Gb/s [6]. Nowadays, the RoF (Radio over Fiber) technology allows the interconnection between wireless and optical transmissions. Thus, it is possible to transmit on optical fibers electrical signals according to different standards, for example allowing the connection with GSM, UMTS, WiFi or satellite.

The two network architectures selected for this mobile service are illustrated in Figure 1, where, on one hand, the wireless network (IEEE 802.11ac) and the optical fiber network are interconnected via a RoF connector capable of converting an optical signal into an electrical signal or an electrical signal into an optical signal. On another hand, the mobile-to-mobile ad-hoc built with Bluetooth technology (IEEE 802.15.1).
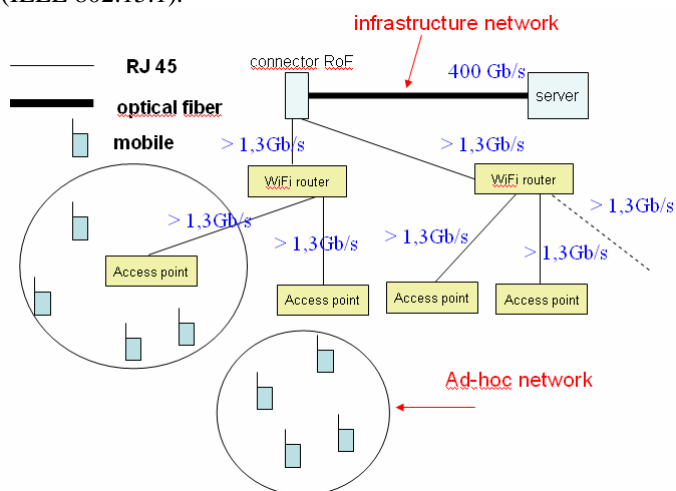

Figure 1: Network architectures

The WiFi router and the WiFi access point (hotspot) communicate according to the IEEE 802.11ac standard which allows to reach theoretical throughput from 1,3 to 7 Gb/s, contrary to the IEEE 802.11n standard which allows to reach a maximal throughput of 600 Mb/s. Standardized in 2013, the IEEE 802.11ac standard introduced some techniques capable of strengthening the performance of the standard IEEE 802.11n published in 2009 [7-8]. Among the evolutions we can note some technical characteristics:

- Multiple users with Beamforming,
- Bandwidth of 80 MHz and 160 Mhz,
- Multiple inputs and outputs up to eight,
- Access to the medium EDCA (Enhanced Distributed Channel Access) enchanced.

Table 1 below provides a simple comparison of the characteristics of the IEEE 802.11n and 802.11ac.

As shown in Figure 1, a RoF connector can connect to multiple wireless routers and each WiFi router can connect to multiple wireless access points. Each access point forms a wireless communication cell, where mobiles connect to the wireless-optical network. As the wireless indoor connectivity depends on its layout, we consider here that each room of the museum is equipped with an access point. In this case, the mobile of visitor can connect to the museum server using the IEEE 802.11ac wireless network through the fiber optical network. Thanks to the high throughput, the museum server is able to provide high-quality multimedia contents requested by many visitors.

	IEEE 802.11ac	IEEE 802.11n
Frequencies	5GHz	2,4GHz & 5GHz
Bandwidth	20, 40, 80MHz (160 MHz option)	20 & 40MHz
MIMO	from 1 to 8 in upload, from 1 to 4 in download	from 1 to 4 in two ways
Density modulation	256-QAM	64-QAM
Filters	Spatial filtering	-
Code rate	5/6	5/6

Table 1: Main characteristics of the standards IEEE 802.11ac and 802.11n

Note that MIMO (Multi Input Multi Output) aims to transmit simultaneously multiple flows based on the number of available antennas. IEEE 802.11ac standard introduces up to eight streams in the uplink direction.

Recall that the Bluetooth technology (IEEE 802.15.1) implemented at each smart phone allows building a mobile-to-mobile ad-hoc network. With Bluetooth V.4, the theoretical throughput allows to reach a maximal 24 Mb/s. As Bluetooth is based on a master-slaver structure, our mobile service uses DSN (Network Service Discovery) to form an ad-hoc network with mobiles at the same cell.

III. COMPUTATION AND CHOICE OF VISIT COURSE

We assume that every visitor is equipped with a smartphone connected to the LAN of the museum with an application dedicated to guide the visitor (presented in the next section) throughout the visit in the museum. We focus in this section to the computation of the tour offered to the visitor in order to see artworks in the museum which correspond to its interests. The computation is performed following two steps, first the visitor has to enter a set of information for artworks selection, and then in a second step the tour is computed.

A. Artworks selection

We consider that the museum has a server with a database storing all the information on the artworks in the museum. Among the available information, we have access to collections' categories, year, author and artwork location in the museum. To select a set of artworks to be considered in the tour, the application first asks to the visitor to answer a few questions before starting its visit. For example, what is the maximum duration of the visit? Which epoch or particular authors he is interested in? How old is he? Is he a person with reduced mobility? The answers to these questions will be sent to the museum server in order to select a collection of artworks corresponding to the given criteria. These information are used to determine a specific tour which is then proposed to the visitor.

B. Computation of the tour

To be able to define the proposed tour, it is first necessary to model the museum as well as all the exposed artworks. This allows then, given all the artworks to include in the tour and their positions, to determine the path that the visitor must follow to see each of these artworks.

1) Artworks and museum modelling

To model the museum and the artworks, we chose to use the graph theory. Indeed, this theory was widely used in several domains, as for example in computer science, biology or chemistry, for the modelling of practical problems to develop algorithms calculating practicable solutions. A *graph* $G=(V,E,w)$ is composed of a set of vertices V, a set E of edges connecting those vertices and a weight function for each edge [12]. The edges of the graph can be directed (unidirectional traffic) or undirected (two-way traffic). For example, for a road, the network vertices may represent the cities, the edges possible routes between these cities and each edge weight function $w(v_1,v_2)$ returns the distance from the direct route (v_1,v_2) connecting the two cities v_1 and v_2. For a museum visit, the modelling of the artworks has to reflect the point of view the visitors can have when seeing an artwork. This is natural for an artwork for which the only way to see it is to be in front of the artwork. However, this is not always the case for an artwork in 3D, which can have multiple perspectives revealing different information to visitors. Thus a position must be associated to each perspective of the artworks in the museum. In addition, *specific points* of the museum space are required in the model to allow the access to a part of the museum in order to compute a practicable route for the visitor, such as input-output of each room, the corridors, the

intersections, etc. So all these points (viewpoints of each artwork and special points of the museum) define the vertices of the graph modelling the museum. The edges of the graph correspond to corridors or staircases connecting two adjacent rooms, but also between the neighboring artworks placed in the same showroom. Two artworks are considered neighbors in a room where there is no obstacle or other artwork in the plane between them. Finally, it is necessary to define the weight function w associated with the edges of the graph. By default, this function will represent the distance in the museum between two vertices (points of view or specific points). This feature meets the triangle inequality property, since we consider the distances in a Euclidean plan. The satisfaction of this property simplifies the computation of a route. However, this function may reflect other interesting information on the link between two nodes, such as the number of steps (for staircase) between two vertices. From an IT perspective, the graph modelling the museum can simply be stored on the server using an adjacency matrix, having a row and a column associated with each vertex of the graph and the intersection between a row and a column of the matrix stores the weight of the edge between the two vertices. The weight associated with the link between a vertex to itself is of infinite value in the matrix because this link is useless to consider for our application.

2) Computation of the route

The last phase is to compute the path to follow for the visitor to see all the artworks selected in the previous phases. Given the visitor's starting point (reception of the museum, for example), we need to compute the shortest path between each of the selected artworks and allowing to pass once at each artwork. Note that we consider that every selected artwork must be seen once by a visitor during a tour. From a theoretical point of view, this is modeled by the *Travelling Salesman Problem* [13]. This problem was first introduced to address the problem of computing the shortest route to visit once a list of cities. Unfortunately, this problem is difficult to solve. Indeed, the problem of the Hamiltonian Path, simplification of travelling salesman problem in which edges have weight values equal to one, has been shown to be NP-hard to solve [14]. That is to say, it is not possible to find an optimal solution in polynomial time according on the size of the graph. Christofides [15] proposed a polynomial algorithm to compute an approximated solution compared to the optimal solution for any graph with edge weights satisfying the triangle inequality. Although this algorithm gives an interesting guarantee, it requires intermediate steps in the computation performing transformations on the graph which are not trivial to implement. There is another simple algorithm which computes an approximated solution for this problem, the Nearest Neighbor algorithm (*NN – Nearest Neighbor*). Given a current vertex in the graph, this algorithm selects at every step the nearest not yet visited vertex. The algorithm starts from the vertex representing the starting point and ends when there is no more non-visited vertex. Rosenkrantz and al. [16] have shown that this algorithm has an approximation ratio of $O(log_2(|V|))$, with $|V|$ the number of vertices. This algorithm must be applied to a complete graph $G'=(V',E')$, built from the original graph G modelling the museum as

follows. For each point of view of an artwork corresponds a vertex in V' (and adding two vertices corresponding to the starting and end point for the visitor). There is an edge between any pair of vertices v_1, v_2 in V' whose weight is equal to the sum of the weights of the edges constituting a shortest path between v_1 and v_2 in G. Given a solution S returned by the NN algorithm, we can compute the final path in the graph G to propose to the visitor by mapping for each edge in E' selected in S the corresponding shortest path in G. The route computed as described above by the server is then sent to the visitor on his smartphone so that he can begin its visit.

3) Adaptation of the tour

Note that at any time the visitor can choose to not follow the route calculated by the server because it can be interested in another artwork that has not been selected in the tour. We consider that the application can monitor in real time the location of the visitor throughout his visit in order to detect if it does not follow the tour, or is simply lost. When such a situation is detected by the application on the visitor's smartphone, the application send again the request to ask the server to compute a new route for the selected artworks not yet visited. The server can apply the same computation by considering the current visitor's position as the starting point, in order to propose a new route to continue his visit. This process can also be applied by considering the case where the visitor wishes to change his interests during his visit. At any time, the visitor can access the menu allowing him (her) to change the answers to the questions given before starting the visit. As a consequence, the computation of a new route is started again by selecting a new group of artworks, while considering the current visitor's position as the starting point of the tour.

IV. MOBILE APPLICATION

A. Description of the features

A prototype of the Android mobile application has been developed. This one allows the visitor, to select a course which interests him (her) according to the work in front of which it is, to obtain the information he wishes. Several tours are proposed to the visitor according to its interests, or according to the amount of visitors in the museum. Figure 2 shows the first page of the application in which the visitor can choose the category of artworks such as transport, mechanics, etc. The visitor benefits from an assistance and a personalized guide inside the museum. Naturally, the user can decide to interrupt the initial tour, and to select another tour either by stopping the current tour or by resuming a precedent tour.

Our application integrates a Web browser to display the information, the consulted pages are memorized. Moreover, a local Web server and various tools to establish statistics are used.

Figure 2: In the beginning a visitor has to choose one course

Each visitor is identified by using the unique number of the device and if the user allows it, an e-mail address can complete its identifier. The visitor is located on his visit by bluetooth beacons [9], accuracy is sufficient for the tests presented in this article. An accurate position is obtained when the visitor uses NFC tags. The real visit and the presentation of the various documents associated to artworks nearby of him (her) is automatically done within the integrated browser into our application. The delivery of documents for an identified visitor is logged on the server side to allow afterward to make statistics of attendance or borrowed tour for the administration of the museum. Documents delivered by the website of the museum, are stored on the mobile of the visitor. It will allow further analysis after visitor's visit to obtain some statistics (see Figure 3). As a matter of fact, the real course of the visitor is similar to the navigation on the Web server of the museum. Indeed, each click on a link in a web page corresponds to an actual movement of the visitor in one of the showrooms. The download of a document is made either during the visitor's progression or in his (her) request in front of the artwork of interest.

Figure 3: In this room of the museum, a document is available to the visitor. (source : Cnam, musée des arts et metiers)

B. Software architecture and implementation

The information are delivered with the HTTP protocol (Hyper Text Transfer Protocol) by a Web server dedicated to the visits. The downloaded pages are stored onto the visitor's smartphone with the same tree organization as in the museum space (See Figure 5). For media with large size, only the links to the original site are preserved.

The tree of the Web site is deduced from the topology of the museum (See Figure 4), so every visitor, by the rooms which it visits, by the documents on artworks which it consults, defines a course in the museum in the same way as a Web browsing and its history of consulted webpages.
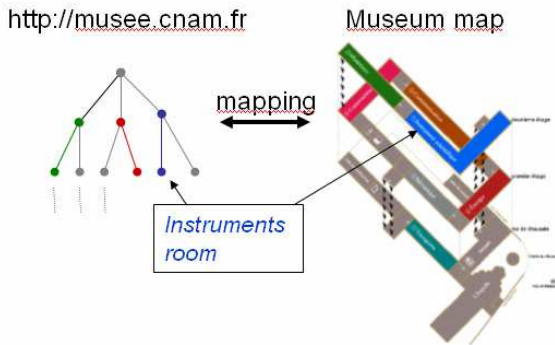

Figure 4: The tree of the website is deducted from the plan of museum

To allow a reading of the course on a smartphone, our application integrates a local Web server (see Figure 5). This new type of local navigation allows to replay the visit on the smartphone after the end of the visit and possibly to start new searches. The overlapping of this effective route with the map of the museum can also be used to prepare a new visit. The identification using an email address, if the user has agreed, allows customization of visits by the museum.
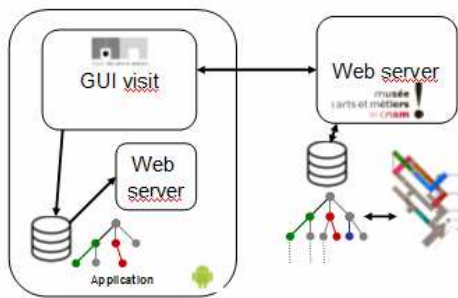

Figure 5: The application is composed of a GUI and a web server

The embedded server on every smartphone, stores the consulted pages, in order to share these ones with other visitors. This represents an optimization of access to the main server of the museum. The NSD (Network Service Discovery) technology is particulary well suited to this kind of service. A downloaded page becomes available by using the NSD service on the smartphones inside the same room.
The following paragraph implements this technology and presents some significant scenarios with experimentations' results.

V. MEASURES

Measures of performances in terms of bandwidth were made in a room of the museum. This room contains an access point, and we have used six mobiles or tablets of different generation:

- A wireless access point using IEEE 802.11ac [17],

- Two Nexus 9 (802.11ac 2x2 MIMO) [18],
- One Nexus 10 (802.11 b/g/n MIMO) [19],
- One Samsung S2 (a/b/g/n) [20],
- One ACER Z200 (b/g/n) [21],
- One ACER Z3 (a/b/g/n) [22].

We retained several significant scenarii. A first scenario, without any optimization and no use of NSD: the six visitors enter the room at the same time and all try to connect to the same webpage of the museum server (cf. Figure 6). The downloaded webpages have two different sizes (12MB note (a) on figures and 1,2MB note (b)). An optimal scenario, in which, three already present visitors deliver to three new incomer visitors the desired webpages (cf. Figure 7). Another scenario consists in the fact that two present visitors deliver to four incomer visitors (cf. Figure 8). And finally any scenario with four incomer visitors and one already present visitor (cf. Figure 9).

The unit of measure is in KB, Kilo-Bytes per second. The measured throughputs to download and a display an HTML document is presented, by considering two file sizes: (**a**) a file of 12 MB size, (**b**) a file of 1,2 MB size. The presented figures are the result of the average over several measures. To start the simultaneous access, a NTP (Network Time Protocol) server has been used.
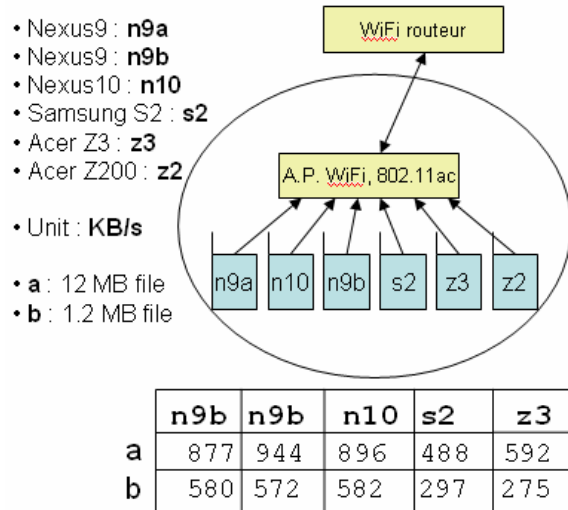

	n9b	n9b	n10	s2	z3	z2
a	877	944	896	488	592	424
b	580	572	582	297	275	220

Figure 6: Six visitors without NSD
(context: simultaneous access, average of several measures)

In the first scenario six visitors download at the same time the same webpage. The measures are directly related with the performances of the server and the access point. An increase of access should keep the same ratio. The performances of tablets come true when big files are downloaded (**b**). This first scenario authorizes a comparison with next presented scenarios which use NSD.
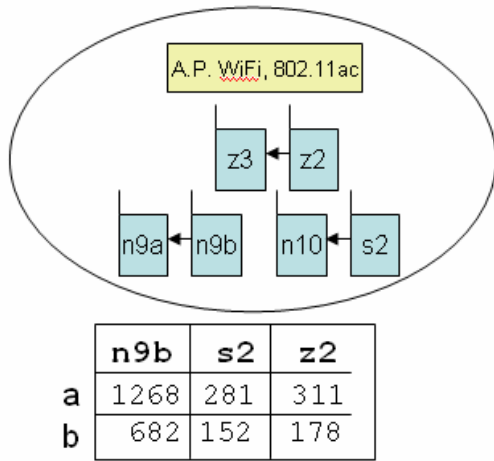
Figure 7: Three clients, three servers with NSD

	n9b	s2	z2
a	1268	281	311
b	682	152	178

In the second scenario, three new visitors download at the same time the same files from three other visitors which are already in the room. The NSD service is used in this scenario. In comparison with the previous scenario, we have better performances between both tablets and Nexus 9 (see Figure 8).

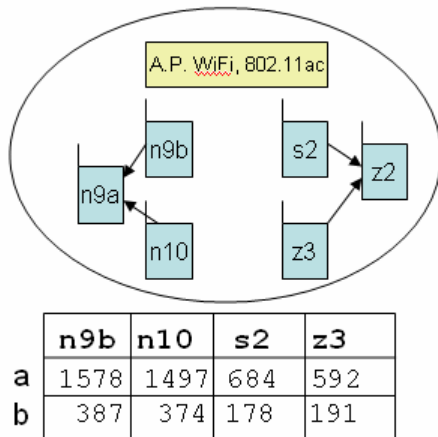|	n9b	n10	s2	z3
a	1578	1497	684	592
b	387	374	178	191

Figure 8: Four clients, two servers with NSD

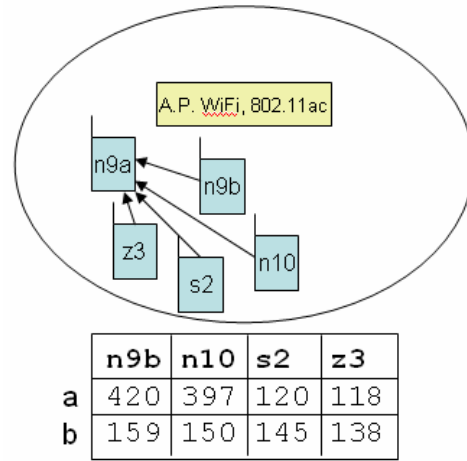Two visitors propose their services, the solution seems satisfactory in terms of performances.

Figure 9: Four clients, one Server with NSD

	n9b	n10	s2	z3
a	420	397	120	118
b	159	150	145	138

In the last scenario, a visitor proposes its services, the solution seems also satisfactory. Note that this architecture is an encouraging step, however, these measures depend on several factors: the position of the antenna and visitors, the number of smartphones, the version of Android.

Table II summarizes the results obtained. The use of NSD technology improves overall performance. This proposed architecture allows de facto increase the throughput of the museum server. Any mobile for visitor can become a server providing the web pages of the primary server for a real parallelism of access to information.

Scenario	NSD	Throughput (kB/s)	
		max	min
fig. 6: 6 clients	no	944	220
fig. 7: 3 clients, 3 servers	yes	1268	152
fig. 8: 4 clients, 2 servers	yes	1578	178
fig. 9: 4 clients, 1 server	yes	420	120

Table II: A summary of the measures

VI. CONCLUSION AND FUTURE WORKS

This paper presents an architecture of networks and a mobile service for interactive guided tour in a museum. The network architecture composed of two parts wireless and optical fiber is described in order to achieve a high throughput allowing visitors to access multimedia resources.

By adapting the criteria for a visitor (e.g., reduced mobility), a dynamic tour adapted to visitor demand is built. The tour is computed using the Nearest Neighbor algorithm. It is shown that this algorithm is well suited to our mobile application.

The NSD technology seems suitable for this type of architecture and this type of service. Experiments have been done and promising performances are obtained. However, new perspectives development could be included into our service. For example, asynchronous notifications by using the push notification service, named "Cloud Messaging Google" [11] or

the accumulation of all the paths chosen by the visitors represents useful information for the museum administration. Presented measurements were made with a small number of visitors in three rooms of the museum. We found that the transmission performance depends on many factors like the number of visitors, etc…

Acknowledgement

REFERENCES

[1] S. leleu-Merviel et K. Kounakou, «Muséo: un visio-guide interactif à l'épreuve», Revue des Interactions Humaines Médiatisées, Vol. 12, pp. 25-65, 2011.

[2] Y. Laurillau et F. Paternò, « CoCicero : un Système Interactif pour la Visite Collaborative de Musée sur Support Mobile », Conférence Francophone IHM'2004, 8 pages. Namur, Belgique.

[3] M. Veyret, E. Maisel et J. Tisseau « Guide virtuel autonome immergé dans un environnement réel dynamique», Revue des sciences et technologies de l'information, Technique et Science Informatiques RSTI-TSI vol.28, pp. 831-855, 2009

[4] http://www.wi-fi.org/, le site officiel de WiFi

[5] Standard IEEE 802.15.4a, 2007

[6] N.Bozinovic, Y.Yue, Y.X Ren, M. Tur, P.Kristensen, H.Huang, A. E. Willner, S. Ramachandran, «Terabit-Scale Orbital Angular Momentum Mode Division Multiplexing in Fibers», Science, n°340, 2013

[7] M-D Dianu, J. Riihijarvi and M. Petrova, « Measurement-Based Study of the Performance of IEEE 802.11ac in an Indoor Environment », IEEE ICC 2014, Sydney, Australia, Juin 2014.

[8] R. Liao, B. Bellalta, J. Barcelo, V. Valls and Miquel Oliver, «Performance analysis of IEEE 802.11ac Wireless backhaul networks in saturated conditions », EURASIP Journal on Wireless Communications and Networking, Springer, September 10, 2013

[9] http://www.smartbeacon.eu/fr/ , le site de SmartBeacon

[10] http://developer.android.com/guide/topics/connectivity/wifip2p.html, Wi-Fi Peer to Peer, Android developer documentation

[11] http://developer.android.com/google/gcm/index.html, Google Cloud Messaging, Android developer documentation

[12] C. Berge, Théorie des graphes et ses applications, Collection Universitaire de Mathématiques II, Paris: Dunod, 1958.

[13] D. L. Applegate, R. M. Bixby, V. Chvátal, W.J. Cook, The Traveling Salesman Problem, ISBN 0-691-12993-2, 2006.

[14] M. R. Garey, D. S. Johnson, "A2.3: ND22–24", Computers and Intractability: A Guide to the Theory of NP-Completeness, W.H. Freeman, pp. 211–212, ISBN 0-7167-1045-5, 1979.

[15] N. Christofides, Worst-case analysis of a new heuristic for the travelling salesman problem, Technical Report 388, Graduate School of Industrial Administration, Carnegie-Mellon University, Pittsburgh, 1976.

[16] D. J. Rosenkrantz, R. E. Stearns, P. M. Lewis, "An Analysis of Several Heuristics for the Travelling Salesman Problem", SIAM Journal on Computing 6 (5): 563–581, doi:10.1137/0206041, 1977.

[17] http://www.dlink.com/fr/fr/home-solutions/connect/access-points-range-extenders-and-bridges/dap-1665-wireless-ac1200-dual-band-access-point, Wireless AC1200 Dual Band Access Point.

[18] http://www.google.com/nexus/9/.

[19] https://support.google.com/nexus/answer/2840623?hl=fr.

[20] http://www.samsung.com/fr/consumer/mobile-phones/smartphones/galaxy/GT-I9100LKAXEF.

[21] http://www.gsmarena.com/acer_liquid_z200-6422.php.

[22] http://www.gsmarena.com/acer_liquid_z3-5624.php.