Collaborative Wireless Access to Mitigate Roaming Costs

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***Abstract*— Environments such as ski slopes are highly dynamic, as users are constantly moving at high speeds and in different directions, and also many users are foreign tourists, not locals, thus having to roam if they want to access the Web. Unfortunately, this introduces costs that discourage the roaming users to connect. In order to solve this issue, a collaborative wireless access service has been designed and implemented on Android. Simply put, locals to the environment become hotspots on-the-fly thanks to our application, which works on all recent Android smartphones, without requiring to root the smartphone, which shares their mobile data access with the foreigners for the period of time that they are in range whilst legally protecting the sharer from any potential illegal use of the foreigner, e.g., illegal download of copyrighted music through peer-to-peer. We have validated our service with agent-based simulation results, users feedback through an online survey supported by an EU Future Internet testbed and real performance tests on the ski slopes regarding client-to-hotspot connection times, distance and energy consumption.**

Keywords - Crowd augmented; Wi-Fi; Smart Ski; mobility; wireless access; simulation.

I. INTRODUCTION

According to the International Telecommunication Union (ITU) and Juniper Research [1], the number of subscribers using mobile Internet services is going to rise from the current 577 million to an impressive 1.7 billion users by 2013, accounting for almost the 50% of the world's Internet usage. This previous fact and the emergence and fast growth of applications such as social networking, user generated content, location services, collaborative tools, augmented human and augmented reality applications etc., has fueled the user's need for permanent connectivity wherever she/he is, and under any circumstances.

While in regular day-to-day environments this need can be fulfilled with regular wireless access provided via hotspots (wireless access points) or mobile data transmission technologies, highly dynamic and changing environments have different requirements that might not be fulfilled with regular hotspots [10]. Also, situations on which the user is on roaming (does not have access to his mobile operator because of being in a different country or out of the area of network coverage), might deter the user to connect through such previous mentioned mobile technologies, as the cost can be very high.

TEstbed for Future Internet Services (TEFIS) [2] is a large-scale integrating project, which will support Future Internet of Services Research by offering a single access point to different testing and experimental facilities for communities of software and business developers to test, experiment, and collaboratively elaborate knowledge. As a part of TEFIS, the Smart Ski Resort experiment run in Megève during 2011/2012 and 2012/2013 winters aims to launch the next generation of intelligent ski resorts providing them with mobile applications and with the resources to create a sustainable development. For our testing purposes, we have used the Smart Ski Resort experiment to obtain the performance results shown later in Section V.

Environments such as ski slopes are highly dynamic, as users are constantly moving at high speeds and in different directions, and also many users are not locals, thus having to roam in order to be able to connect through mobile data. These two previous reasons make connectivity through regular means to be difficult to attain, thus impeding the use of such smart mobile applications, augmented reality applications, or the mere upload of data and statistics for user tracking or measuring purposes.

In order to solve such a challenge, we have envisioned a crowd augmented wireless access [9]. Simply put, locals to the environment become hotspots on the fly, sharing their mobile data access with a foreigner for the (rather short or not) period of time that they might be in range. In this way, all the foreign skiers in the slopes, and more broadly speaking foreigners in general, are still able to upload fundamental data and statistics and even use applications on places where normally they would not be able to get connectivity through their own means or would be too expensive to do so. All of this, without having to deploy real fixed wireless access points and signal amplifiers, and not limiting the area of coverage, as the access points are carried by the local people, which might be static or on the move. In this paper, we present the technical feasibility and performance results of our collaborative wireless access service, which also legally protects the sharer from any potential illegal use of the connection done by the foreigner, e.g., illegal download of copyrighted music through peer-to-peer. However, the description of how we legally enforce the protection of the sharer is beyond the scope of this paper.

The rest of the document is organized as follows. First, Section II presents the related work and then Section III describes the simulation experiment and presents the results obtained from it. After, Section IV presents the user survey feedback regarding several aspects on roaming, costs, and risk awareness. Next, Section V shows quantitative assessment in terms of performance of the Android application tested in real scenarios, both a dynamic one, in the ski slopes, and static one, in a cafeteria. It also presents performance results regarding battery consumption and CPU usage. Finally, Section VI concludes the paper.

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II. Related Work

There are several applications and projects that aim as well to enable and to make easier the task of sharing a mobile data access through Wi-Fi in order to solve similar challenges as the ones we want to tackle.

Air Mobs [3] is an application that enables users to share their excess data with users who might be running up against their monthly limits. Essentially, one user agrees to let their mobile device act as a tethering hub that will send data from their LTE smartphone over Wi-Fi to any users nearby. In exchange, the central hub user gets a “data credit” that gives them access to other users’ data in the future. Put another way, the new app creates a sort of “cap-and-trade” market for mobile data that helps users exceed the hard limits set on their consumption by rationing data with one another based on their needs at given times. Compared to our solution, it does not provide any sort of protection for the sharer against any risk that might arise from the sharing and it does not provide a WPA2 secured connection.

The Open Garden application [4] application enables users to access the most appropriate connection without configuring their devices or jumping through hoops. It also enables users to access Internet as cheaply as possible. Users can find the fastest connection and most powerful signal without checking every available network, and can move between networks seamlessly. Open Garden provides a way to access more data at faster speeds in more locations. Consumers actually become part of the network, sharing connections when and where they provide the best possible access. Compared to our solution, it does not provide any sort of protection for the sharer against any risk that might arise from the sharing and it does not provide a WPA2 secured connection.

The User-Centric Local Loop (ULOOP) [5] FP7 European project brings in a fresh approach to user-centricity by exploring user-provided networking aspects in a way that expands the reach of a multi-access backbone. ULOOP addresses the user as a key component of networking services in future Internet architectures. Building upon current (commercial) examples ULOOP explores not only the adequate technical sustainability of user-centric models, but also legislation implications and the potential of community-driven services and how these new aspects may give rise to novel business models both from a user and from an access perspective. The aim of ULOOP if to seamlessly expand the backbone of the network through the end users’ devices, extending the area of coverage while offloading the often saturated provider networks [11]. From a preliminary assessment, we believe that the project functionality is not yet mature enough and fully developed, and that they do not provide legal protection for the sharer as well.

III. Simulation

This section presents the simulation experiment in order to preliminarily evaluate the feasibility of the real application and the results obtained from running the simulation.

A. *Simulation Experiment*

The experiment shows the simulation of a ski slope, with local skiers which have connectivity through 2G, 3G, etc. and foreign skiers which in principle do not have connectivity of any kind. The simulation has been carried out using Any Logic’s [6] agent based simulation capabilities, assigning real values and proportions to the scenario.

When the simulation is started, an introduction screen that depicts the scenario and asks for the skier concentration rate is shown. The concentration rate defines how busy the ski slopes are, and thus influences the availability of connectivity for foreign skiers. It ranges from 1 (not busy), which will deploy zero to one skier, either foreign or local, for each ski lift arrival, to 4 (very busy), which will always deploy four skiers (maximum ski lift capacity) per ski lift arrival. The foreign-to-local skier’s ratio is 30%-to-70%, in order to reflect the real statistics of Megève ski resort.

The ski lifts are modeled with a discrete-event approach, having the appropriate inter-arrival time and speed. Every time one ski lift arrives to its “sink element”, 3 skiers are deployed according to the concentration rate, as explained previously. We have chosen 3 as the concentration rate as it reflects a moderately full ski resort, which is the case we want to analyze. When the skiers are deployed, they are assigned an initial random speed, which ranges from the slowest to the highest average speed of a regular downhill skier, which ranges from 25 to 40 km/h, and a final destination at the end of the slope. In order to make the simulation more realistic, the trajectory between the deployment point to the end point is not set as a straight line but as a sinusoidal function which imitates the real movement of a skier. The ski slope’s length is set to 800m and the width to 80m, as it is a good estimate of the length of a typical ski slope according to Megève Tourism board and Megève ski lifts’ company.

Foreign skiers’ terminals scan for access points, and when they are in range of one (or many) of them, they try establishing a connection as depicted in the process of Figure 1. The range of the portable access points has been set to 40 meters in the simulation, as it is the typical average value of that of a mobile device such as an Android or an iPhone terminal, and besides it has been confirmed through real experimentation cases as explained afterwards in Section V.A.

The aim of the simulation is to measure how effective a solution of this kind can prove to be in a highly dynamic environment such a ski slope, as if it is working in such an environment, it will also work in a more static environment such as a bar or a local shop. In order to study the feasibility of our approach, we measure for each foreign skier his or her connectivity duration time and their connectivity status, be it “connectivity setup” or “connected”.

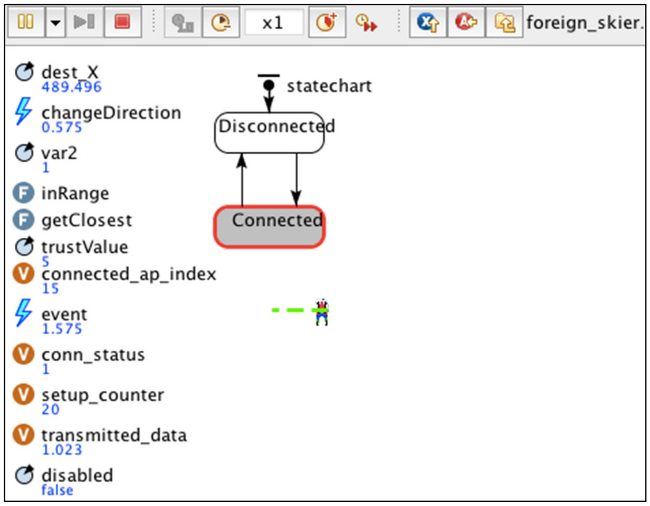

Figure 1. Foreign skier state chart and events.

Once connected, the foreign skier proceeds to transmit for the duration of the connection (assuming regular 3G/HSDPA rates), and when she or he is disconnected the process starts over again until the skier reaches the end of the slope and goes into a ski lift. This full simulation process is depicted in Figure 2, where local skiers are represented by blue avatars surrounded by a green circle which displays their portable hotspot range (as previously said set to 40m), foreign skiers as red avatars, and the connectivity status between them is represented by dashed lines, yellow in the case of a connection setup ongoing and green in the case of an already established connection.

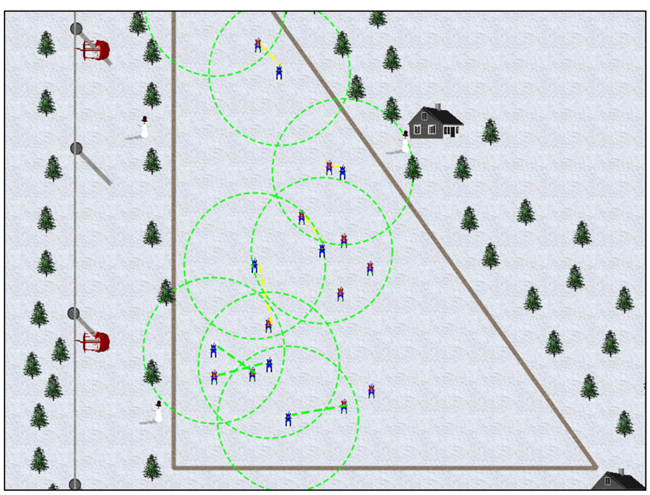

Figure 2. Main simulation screen.

Connectivity setup time has been set up to 50 seconds, as it is what we expect our application to perform like. The following section presents the results derived from the simulation.

B. Simulation Results

In order to study the feasibility of a real application on the ski slopes, we have measured during simulation experiments 3 sets of different data. For all the graphs, the X axis represents the simulation time:

- Global amount of foreign and local skiers in the ski slope at any given time of the simulation.
- Amount of foreign skiers in "connection setup" state vs. the amount of foreign skiers in "connected" state at any given time of the simulation.
- The maximum amount of time a skier has been connected at any given point of the simulation time and the global average time a skier is in "connected" status.

The first graph, depicted in Figure 3, shows the statistics for the global amount of local and foreign skiers present in the simulation slope at any given point of the simulation time, being the X-axis the time and the Y-axis the amount of skiers. As can be seen in the graph, the amount of local skiers ranges in average from 30 to 40 while the amount of foreign skiers ranges from roughly 10 to 20. This gives a ratio of approximately 67% of local skiers and 33% of foreign skiers, which adequately reflects the real ratio between French local skiers and foreign skiers in Megève ski resort according to Megève Tourism board. As can be inferred from this numbers, the total amount of skiers in the slope at any given point of time ranges from 50 to 60, which is a realistic measure for what a moderately busy ski slope would look.

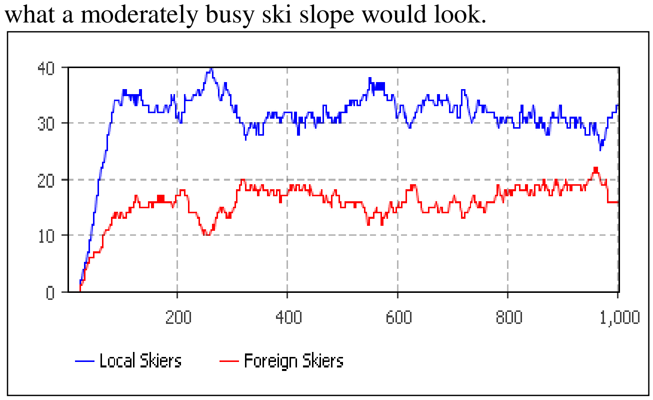

Figure 3. Amount of local and foreign skiers in the slope at any given point of the simulation time.

The second graph in Figure 4 shows the amount of foreign skiers that are setting up a connection with a local skier versus the amount of foreign skiers that are already connected and thus, transmitting data, being the X-axis the simulation time and the Y-axis the amount of skiers in each of the two states. As can be seen in the graph, from the 10 to 20 foreign skiers present in the slope at any time, around a 20%-25% have an established connection, while 70%-75% are into "connection setup" state. The remaining percentage accounts for those who have no local skier to try to connect to. This data correlates properly both with the total amount of foreign skiers present in the slope at the given simulation time and with the expected results of the simulation, as the connection setup phase takes 50 seconds, thus allowing only skiers that have been for at

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least those 50 seconds in the slope to have an established connection.

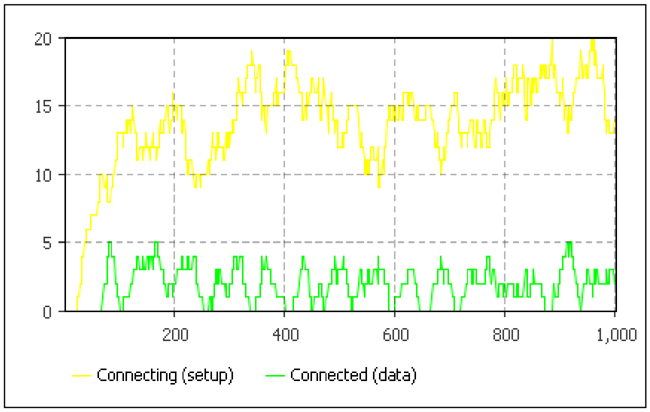

Figure 4. Amount of foreign skiers in connection setup and connected states at any given point of the simulation time.

Finally, the third graph in Figure 5 shows the maximum amount of time (in seconds) a skier has been already connected in a given point of time, and the global average of the time (in seconds) skiers in general are in a connected state, being the X-axis the simulation time and the Y-axis the amount of seconds of achieved connectivity. We can see in the graph that in average, skiers are connected during 10 seconds to a local skier, reaching maximum connection times of over 20 seconds. This fits into the expected results, as the speed of a foreign skier is in the 25 to 40 km/h range as previously said before, which makes an average speed of 32.5 km/h (9 m/s). Taking into account that the length of the slope is 800m, we can establish that it takes nearly 88 seconds to complete the full length of the slope.

A perfect descent would imply that the foreign skier is in "connection setup" state for 50 seconds, having 38 extra seconds to be in a connected status, but taking into account that the trajectories and speeds of the skiers in the slopes are not uniform, that connectivity setup can start later in time than when the skier first reaches the slope and that the connectivity setup phase can be broken if the foreign skier goes out of the area of coverage of the local skier's hotspot, we assume that the results obtained in the simulation adjust to the reality of the situation well, deeming them as valid.

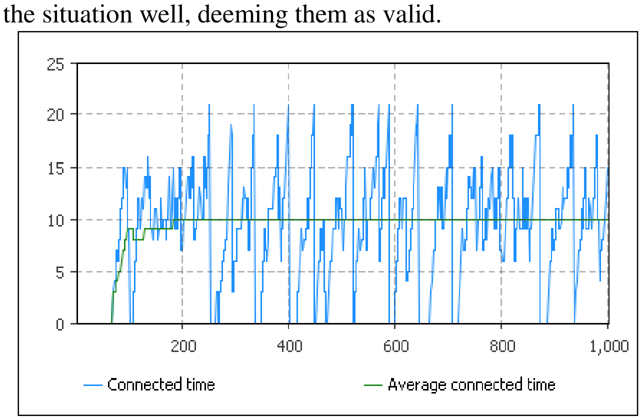

Figure 5. Average connected time for any foreign skier during the simulation time.

All in all, the results obtained in the simulation phase imply that such an application is feasible, as foreign skiers have enough time to at least do some light data exchange, as the average 3G/4G connection averages real data rates from 200Kbps to 1Mbps [7], in order to for example update slope maps and status in real time, which can take approximately the order of 0.98 to 2.86Mb with a decent zoom level [8] and upload meaningful statistics of an order of a couple of hundred Kbs about speed, distance and such to a server when using a Smart Ski Resort application which offers this capabilities, all without having to take care to connect manually or use their smartphone actively.

Also, these results imply that in a static situation, such a local cafeteria, restaurant or shop, connectivity would be obtained without any significant problem, as the situation is much less demanding than that of a ski slope.

IV. USER SURVEYS FEEDBACK

In order to estimate the need and awareness of users regarding Wi-Fi sharing and to determine which mobile platform would be the best to deploy our application, we carried out three sets of surveys with the real users in Megève ski resort thanks to Megève Tourism board. The first one aimed at determining the best mobile platform, both taking into account the amount of users and technological constraints inherent to the platform itself, the second one to better understand the needs, requirements and risk awareness of the users regarding Wi-Fi sharing and the third survey, that was carried out on a marketing database of users who are interested in computer programming in order to cover a broader audience than Megève users, gave more insight regarding that risk awareness of Wi-Fi sharing.

A. First User Survey

In this user survey, we wanted to determine which mobile platform in regards of popularity in Megève ski resort would better suit our needs, while providing the least possible technological constraints, such as API extension, access to system functions and the like.

The survey was carried out was open from the 1st of February to the 5th of March 2012 in the ski resort of Mègeve, and involved the participation of 3458 users, from which 58.7% were female and 41.3% were male, filling out an online questionnaire as can be seen in Figure 6. We worked in collaboration with Megève Tourism board to distribute the online form to as many tourists and locals as possible through its different communication channels adapting the form to each channel: a standard Web form on Megève main Web site, a Facebook form app on Megève Facebook page and a mobile Web version of the form for Megève mobile users. Following TEFIS living lab methodology [2], we motivated the users to fill the form by adding a prize draws. They could win a week-end for 2 persons in a 5-star hotel in Megève including a ski pass as well as ski gears.

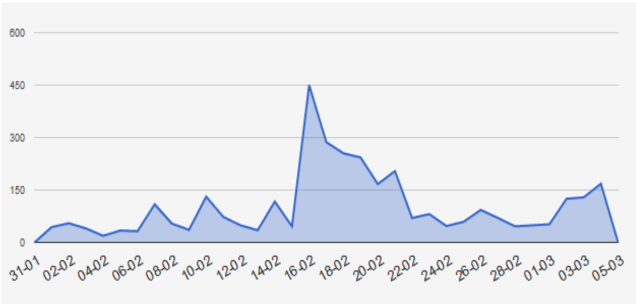

Figure 6. Amount of users filling the survey per date.

From those 3458 users, the age distribution was as depicted in Figure 7 and their preferred mobile OS can be found in Figure 8.

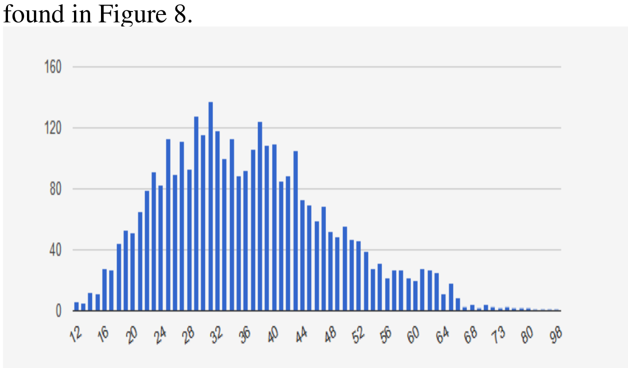

Figure 7. Distribution of users based on their age.

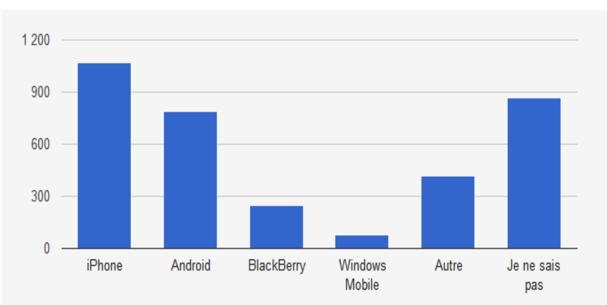

Figure 8. Number of users per mobile operating system.

Where "Autre" means other mobile operating system and "Je ne sais pas" means that the user did not know which mobile operating system she or he was using.

After obtaining these results, and looking carefully to the two most used mobile OSes, namely iPhone (iOS) and Android, we decided that due to the technological constraints which iOS imposes, such as the impossibility to access low-level system functionality and stricter rules in order to place applications in the Apple Store, we would target Android as the mobile operating system of choice.

B. Second User Survey

The second survey, carried out during January 2013 and still online, is aimed at determining the awareness of the users regarding Wi-Fi sharing in general, roaming costs and the risks derived from sharing wireless connections.

Even though the survey contains to the date only the answers of 22 users, it already provides a valuable insight in these matters. The survey is divided into different sets of questions, each set related to one topic. Following, we present the results gotten so far from the survey.

1) General questions

This set of questions is of general purpose, to determine several main characteristics of the users taking the survey. The questions contained in this section are as follow:

1. What country do you come from?
2. How old are you?
3. Which mobile phone operating system do you use?
4. Would you like that we inform you by email if we have a proposal to lower your costs to access the Internet when you are abroad?
5. What is your email address?

We have plotted in a two charts the answers of questions 3 and 4 as they are the only relevant ones for this paper's purpose. Those can be seen in Figures 9 and 10.

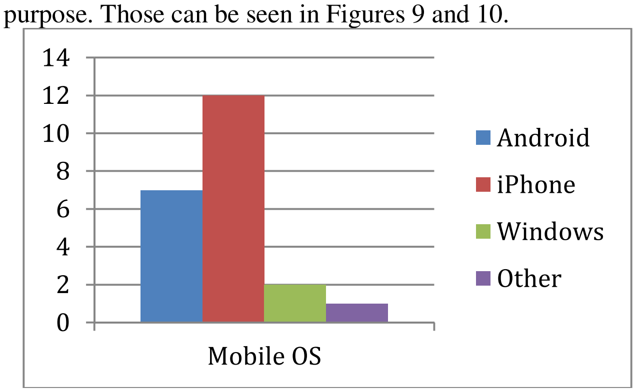

Figure 9. Number of users having filled the form per mobile operating system.

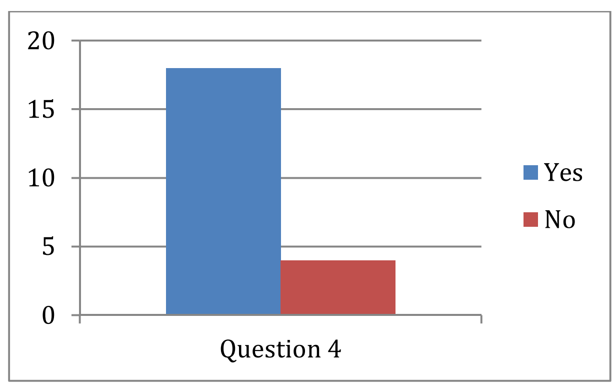

Figure 10. Amount of users interested on updates on our proposal.

2) Roaming cost questions

The goal of these questions is to determine whether the users know the cost associated with roaming and their willingness to still access the Internet even at a cost. The questions contained in this section are as follow:

6. How much do you pay on average for accessing the Web, email and social networks from your phone when abroad during your holidays or a trip?

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7. Would you like to access the Web, email and social networks from your mobile phone when abroad?
8. How much is the maximum that you would like to pay per day to access the Web, email and social networks when abroad?
9. Do you have a special option in your mobile monthly subscription that allows you to access the Web, email and social networks when abroad?
10. How much data can you access with your mobile phone subscription with that extra access to the Web, email and social networks when abroad?
11. How much do you pay in your mobile phone subscription for that extra access to the Web, email and social networks when abroad?

For question number 6, 5 out of 22 users estimated that they pay less than 5 euros to use mobile data when abroad, four said that they pay between 6 and 15 euros, two stated between 15 and 25 euros, two from 25 to 50 euros, and one from 50 to 100 euros. Six users answered that they were too afraid of the cost so they were not using data when roaming at all, and two stated that they did not know how much they were paying.

For question 7, 21 out of 22 users said they would like to be able to use mobile data while abroad, and regarding question 8, the answers ranged in between 0 to 15 euros in order to access the Internet while abroad being the average 5 euros per day.

Regarding question number 9, seven users stated that they had an especial option in order to be able to use mobile data when abroad, twelve did not have any special option and three did not know. From those people with the special option, three of them could use from 16 to 50 MB of data per month while abroad, two from 5 to 16 MB, one from 1 to 5 MB and one did not know how much data while roaming the special option allowed for. Finally from those seven users with the special option, four had to pay less than 10 euros for it and three in between 10 to 20 euros.

3) Wi-Fi sharing questions

The goal of these questions is to determine whether the user knows how much they pay for their data access and if they incur into any extra cost when sharing their mobile data access through a portable hotspot in their own country and also to know the willingness of the user regarding sharing their data access. The questions contained in this section are as follow:

12. Do you know how much you pay to be able to access the Internet in your home country with your current telecom operator subscription?
13. Do you know much data per month you can access in your home country with your current telecom operator subscription?
14. According to your telecom operator mobile phone contract, are you allowed to share your mobile phone data access with your other devices?
15. Do you know what happens if you go over your monthly data access quota with your current telecom operator subscription?
16. Have you already shared your Wi-Fi access in order to let someone else access the Internet?
17. Would you mind sharing your mobile phone access to the Web through its Wi-Fi connection with someone else?

For question number 12, the most common answer amongst users was from 31 to 50 euros per month with 8 out of 22 users, followed by five users paying in between 16 to 30 euros, four users paying below 15 euros per month, one paying from 76 to 100 euros and four not knowing how much they were paying per month.

Answer to question 13 ranged from below 20 MB per month up to 3 GB per month, being the average around 1 GB of data per month. For question 14, eight users were allowed to share their mobile data access with other devices, six were not allowed by their operator and eight did not know whether they could share it or not.

Question 15 most common answer was that the user had to pay if going over the monthly data quota with 8 out of 22 users answering that, six users had decreased speed after passing the monthly quota, three had their data closed until the beginning of the next month and five did not know what happened.

For question number 16, fourteen users had already shared their Wi-Fi access and eight had not, and finally for question 17 eighteen out of the twenty-two users taking the survey stated that they would not mind to share their mobile phone data access through Wi-Fi with either family, friends or colleagues, and four would not share it with anybody.

4) Wi-Fi sharing risks

The goal of these last set of questions is to determine whether the user is aware of the risks associated with sharing her or his own data connection through a portable hotspot, whether she or he would be willing to share it if there were no associated risks and up to which percentage of their data allowance they would be willing to share free of risk. The questions contained in this section are as follow:

18. Did you know that you take risks when you share your Wi-Fi access with someone else because she/he could carry out illegal actions such as illegal download of copyrighted music?
19. Due to those risks to share your Wi-Fi connection, would you decide not sharing your Wi-Fi connection?
20. If a new way of sharing your Wi-Fi access without the risk for you to be responsible for the illegal actions that the person might do through the connection, would you share your mobile phone Wi-Fi connection?
21. How much percentage of your monthly mobile data access would you be prepared to share if there is no legal risk for you and it contributes to the tourism quality of service of your region?
22. How much percentage of your mobile monthly data access would you be prepared to share if there is no legal risk for you and you are in return paid more than what your data access costs?

For question number 18, nineteen out of the twenty-two users stated that they know they take risks when sharing their Wi-Fi access, while three answered no. Regarding question 19, twelve users said that due to those risks they would consider not sharing their Wi-Fi connection while ten would still share it.

In question 20, fourteen users would share their Wi-Fi connection if they would not be legally responsible for any illegal action performed by the person they would share with, while eight still would not share it.

Finally, for question 21 users would be willing to share from a 10% to a 90% of their monthly data access and in average a 35.75% if it would contribute to the tourism quality of their region, and in question 22 users would be willing to share from a 10% to a 100% of their monthly data access and in average a 45% if they would be paid more than what their data access costs.

C. *Third User Survey*

During summer 2012, we created a short survey and sent it to a list of users who are subscribed to a marketing database and who are interested in computer programming and speak English or French. 1767 users answered, which is quite a large number of answers. We asked them the following question "Do you know that a Wi-Fi hotspot public access point name can be easily impersonated and that it can be a security risk for you?" They could reply one of the following answers "Yes; No; I don't care" and optionally add a textual comment. 5 of them used that comment option and answered: yes with the following comment "but it is possible to secure the link"; yes with the following comment "VERY COMMON AND IT CAN CAUSE HAVOC!!!!!" yes with the following comment "Obvious: P"; yes with the following comment "Honeypot :-)"; no with the following comment "Yes, now I know :P". Among the English speaking people, 540 replied "yes", 185 replied "no" and 1017 replied "I don't care". The image below on Figure 11 indicates the percentages for each answer type.

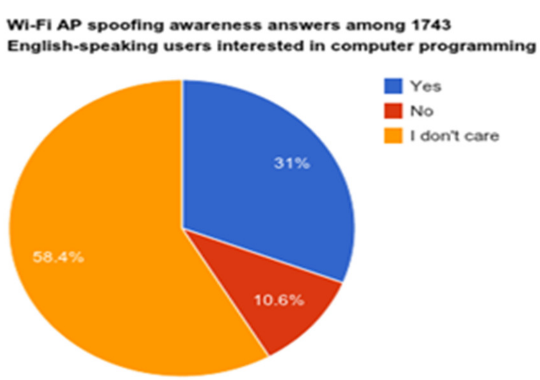

Figure 11. Answers for question 4.

Although these users are interested in computer programming, it is surprising to see that 58.4% of 1743 English-speaking users did not care really care about this issue and that 10.6% did not know it. Concerning the comment on securing the connection, few users would know how to really secure their connection. Furthermore, the fact that many of them answered that they do not care, leaves us to think that they would not take the time to secure it if it is not automated, which is not the case today with current Wi-Fi connections. It is the reason that we decided that our Android application would automatically share the Wi-Fi connection with encryption (such as the one provided by WPA2) enabled by default.

V. FEEDBACK FROM APPLICATION REAL TESTING

In this section we present the performance results obtained when testing the real Android application both in the ski slopes and in a cafeteria, plus some preliminary tests about Android portable hotspot connectivity range.

As said above at the end of Section IV.C, we have chosen to protect the connection between the foreign skier Android phone and the local skier Android phone sharing its connection through Wi-Fi with WPA2 security. Unfortunately, it is longer than a normal non-encrypted client-to-hotspot connection but we needed to know how much longer it would take and if it was still compatible to share while moving and skiing on the ski slopes.

Once a stable prototype of the application was achieved, we proceeded to test it under real conditions. In order to do this, we performed tests in Megève ski resort located in France, both at the slopes while skiing and in a cafeteria, while not moving at all.

A. *Client and Hotspot Measurement Results*

In order to determine the required parameters for both the simulation and the real application, we have carried out a few simple tests to determine the range of a portable hotspot such as the one present in Android phones. Table I shows the results from these first tests.

TABLE I. PRELIMINARY CLIENT-TO-HOTSPOT DISTANCES AND SIGNAL STRENGTH.

Distance to AP (m)	RSSI
5	-29
10	-57
15	-57
20	-57
25	-57
30	-57
35	-57
40	-57
45	-65
50	-62
55	-57
75	-70
100	-74

As shown in the table, we have tested how the signal strength of the portable hotspot evolves for a set of distances, ranging from 5 to 100 meters, being lower values a better signal strength. As can be seen, the coverage area of such a device goes well up to 100 meters, even though the signal strength is already too low in order to achieve a meaningful and reliable data transmission. Thus, according to this results, we have considered for both the simulation experiment and the real application tests a range of 40 meters maximum, as

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we think it is a realistic approach on what the capabilities of a portable hotspot are.

B. Ski Slope Test Results

In order to perform the tests in the ski slopes, we first divided them into two sets of tests, carried out in two consecutive days. The results of the first day of testing can be seen in Table II, while the results from Table III correspond to the second day of testing.

In the first day of testing, we focused more actively in testing the overall performance and response of the application than in performing intensive data consuming operations (heavy download, HD video streaming, etc.), which was left for the second testing day. As can be seen in Table II we underestimated slightly the connection setup time in the simulation, being sometimes higher than the previously 50 seconds used. Nevertheless, we obtained good results while skiing inside the appropriate distance which the hotspot covers, achieving connections lasting up to 5 minutes and a good amount of data download and upload.

The short lived connections present in the table account for the cases where either the connection setup phase broke due to surpassing the adequate distance in between the skiers or due to the local skier not having mobile data connectivity at the moment, or due to automated sharing protection mechanisms not being established properly during the setup phase, or due to HSDPA to 3G failover or vice versa.

TABLE II. UPLOAD, DOWNLOAD, CONNECTION SETUP TIME AND CONNECTED TIME IN THE SKI SLOPES, 1ST DAY.

Data upload (Bytes)	Data download (Bytes)	Connection Setup	Connected Time
634744	3719567	1 min, 6 sec	5 min, 18 sec
0	10171	1 min, 24 sec	0 min, 6 sec
641559	11364516	0 min, 40 sec	5 min, 59 sec
0	0	0 min, 55 sec	0 min, 0 sec
203325	2287543	1 min, 40 sec	0 min, 59 sec
6338	24506	0 min, 50 sec	0 min, 55 sec
144730	1151956	0 min, 50 sec	2 min, 49 sec
889	13057	0 min, 54 sec	0 min, 37 sec
1131749	39404562	0 min, 50 sec	4 min, 57 sec
0	3099	0 min, 40 sec	0 min, 19 sec
0	0	1 min, 5 sec	0 min, 6 sec
10580	28864	0 min, 42 sec	1 min, 9 sec
0	72	1 min, 14 sec	0 min, 6 sec
80058	1470702	0 min, 49 sec	0 min, 47 sec
210412	6311026	0 min, 44 sec	0 min, 55 sec

We dedicated the second day of testing to perform more controlled and more data intensive experiments, trying to stay at all times inside the appropriate range to the local skier while performing data consuming tasks such as HD streaming and the like. We aimed to maintain long lived connections (as long lived as can be while in a ski slope and a ski lift) to see how the application would perform, even though we still got some short or non-existent connections due to the facts previously mentioned previously in the first testing day. The results can be seen in Table 3.

TABLE III. UPLOAD, DOWNLOAD, CONNECTION SETUP TIME AND CONNECTED TIME IN THE SKI SLOPES, 2ND DAY.

Data upload (Bytes)	Data download (Bytes)	Connection Setup	Connected Time
0	11215	0 min, 41	0 min, 6 sec
713780	24391110	0 min, 47 sec	7 min, 56 sec
3161848	102125792	1 min, 18 sec	13 min, 18 sec
1234	9215	0 min, 45	0 min, 8 sec
644697	22112428	0 min, 44 sec	6 min, 39 sec
0	0	0 min, 56 sec	0 min, 0 sec
148083	1547139	1 min, 32 sec	29 min, 18 sec

As shown in the table, we successfully achieved to maintain quite long connections (up to almost 30 minutes), while skiing and in the ski lifts. Also, it was possible to upload and download a good amount of data without further problem while being connected, streaming HD video and browsing internet.

C. Cafeteria Test Results

To finalize the set of tests, we carried out a session in a less dynamic place than the ski slopes. We tested the application in less demanding and more static conditions by performing some tests inside a cafeteria of the ski resort while not moving any of the terminals at all. The results of these last set of tests can be seen in Table IV.

TABLE IV. UPLOAD, DOWNLOAD, CONNECTION SETUP TIME AND CONNECTED TIME IN A CAFETERIA.

Data upload (Bytes)	Data download (Bytes)	Connection Setup	Connected Time
551012	2611660	0 min, 46 sec	11 min, 40 sec
590794	2528282	0 min, 46 sec	8 min, 27 sec
0	5460	0 min, 53 sec	0 min, 2 sec
468920	1916792	0 min, 47 sec	4 min, 25 sec
1227882	4608589	0 min, 52 sec	6 min, 16 sec
0	3465	0 min, 59 sec	0 min, 0 sec
1321702	3829081	1 min, 30 sec	21 min, 27 sec
1118089	3206335	0 min, 57 sec	55 min, 30 sec
265781	1844596	0 min, 48 sec	19 min, 7 sec

As displayed in the table, we were able to achieve long lived connections, up to 55 minutes without it breaking, and

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successfully doing light browsing and casual social network and app use. Again, some of the shorter or broken connections account for the cases where either the local phone lost connectivity or switched from one type of network to another, deeming impossible to perform the appropriate steps in order to protect the user sharing her or his mobile connection, or to establish a connection at all.

D. Battery and CPU Usage Results

In order to assess the performance of the application regarding battery consumption and CPU usage, we measured those values using the built-in functionality to monitor per application battery and CPU usage that can be found in any Android phone. High battery consumption values could deter users from adopting our application in the future, and thus were of a high concern for us.

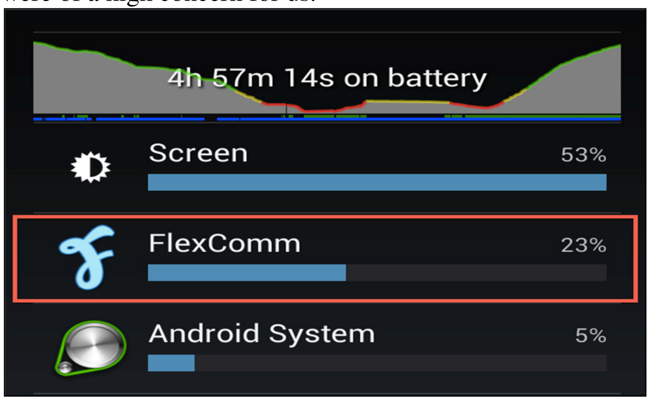

Figure 12. Percentage of battery consumed by the Android application service.

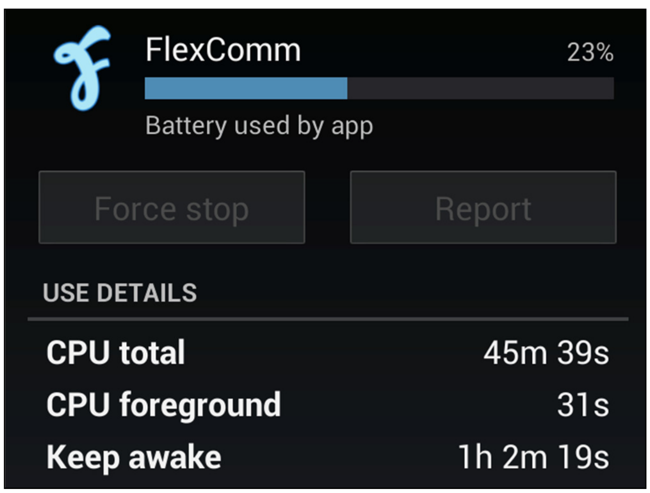

Figure 13. CPU statistics for the Android application.

As can be seen in Figure 12 and Figure 13, the battery usage during the testing sessions falls inside an acceptable range, accounting for the 23% of the total battery use, while the CPU usage both while performing active operations and just in a keep awake status are also inside acceptable values. This said, the battery usage level could and should be improved not to impact the overall user experience and this is one of the points we will work in following versions of the application.

VI. CONCLUSION

In this paper we have presented a complete simulation and real testing results for an Android application to achieve collaborative wireless access to mitigate roaming costs while protecting the sharer.

Both the simulation and the real testing results plus the data acquired from the surveys are encouraging and prove the feasibility and need of such an application. In terms of connection ranges, hotspots perform well up to 50m range, and regarding connection establishment times and data upload, our results show that the times and amount of data are enough to make the system reasonably useful. Finally, regarding battery and CPU consumption results are inside acceptable ranges for the app to be usable.

Future work will involve improving the application in order to solve some of the drawbacks found from the testing sessions, such as better detection of actual connectivity failure, ensuring that the local phone switching from and to different networks does not introduce false positives, better battery use performance and a desktop client.

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