Abstract—Nowadays people claim and expect pervasive communications, with continuous and seamless media access; that requires new communication paradigms beyond the legacy network- and device-centric approaches, and leads to the user-centric concept.

Mobility is a key issue in pervasive communications, and session migration is the most related aspect with the user-centric vision; however, despite of the fact that the user should be at the center of the system, no evidence of user involvement in the design and evaluation phase can be found in the literature for this topic.

In this paper we describe the user evaluation we carried out by a live demo open to a large heterogeneity of potential users at a national science exhibition. Our purpose was twofold: on the one hand, to evaluate users’ feeling with our user-centric networking mobility framework based on the concept of Personal Address and, on the other hand, to figure out general indications for the whole research community about user’s expectations and requirements for session migration.

Index Terms—Session migration, integrated mobility, user-centric communication, personal address, user evaluation.

I. INTRODUCTION

Modern communication paradigms have gone well beyond the raw packet transport service for which the Internet was originally designed. The latter has radically evolved since its beginning; this change concerns the nature and composition of the traffic but also – and mainly – the way the Internet is perceived by users: today most of the people expect to “interact” with the Internet, not only to retrieve HTML pages or to transfer files.

This evolution has had a deep impact on the masses, with significant social implications, yielding new paradigms of communication in which users are at the center of the network. Nowadays people expect communications to happen in a way that is more tailored to humans instead of machines; the trend is to move from legacy device- and network-centric approaches to the user-centric paradigm. Roughly speaking, technology should go towards users and adapt itself to them, unlikely what has been happening until recently.

One of the key aspect in this evolution is transparent and seamless access to network content and services by users, regardless of their location and the terminal device(s) they are using. That rises new expectations about an effective and flexible mobility support in the current Internet.

There has been an ever increasing interest in bringing mobility into the Internet architecture during the last 20 years, which somehow resembles the evolution discussed so far: initially, the effort was mainly devoted to make devices mobile (terminal handover), whilst in the past decade the focus was on session and service mobility (session migration and service portability). The latter are essential in order to build user-centric pervasive communication environments; however, despite of the large numbers of algorithms and protocols for terminal handover, few proposals are available for session migration.

The main performance issue of mobility frameworks concerns the “seamless” property, which demands for fast and timely execution of the migration procedure. Usually, an upper bound on the communication gap during the handover procedure can be easily derived depending on the application; for example, it is well known that a few hundreds milliseconds of voice conversation can be lost without significantly affecting the understanding of the whole dialog, while for data traffic few seconds of delay may be tolerated before muddling the TCP congestion control up.

The above consideration is certainly true for terminal handover, but things are more complicated in case of session migration: the quality of service perceived by the user depends not only on the media disruption but also
on the current user behavior and context. Indeed, when an active session is migrated from one terminal to another, depending on the relative position of the user and the two devices the user may have to turn his head, to pick up the new device or to move towards the new terminal (if the two devices are not close each other); in all cases, his behavior may hide in part or completely the transition delay.

The main outcome from this reasoning is that session migration should be evaluated both quantitatively (in terms of migration delay) and qualitatively (in terms of user satisfaction). Unfortunately, the latter aspect is very often (if not always) neglected. Nevertheless, user evaluation is crucial while developing user-centric systems, where the interaction between the user and the device is as important as technological issues. Further, quantitative measurements are almost impossible with automatic session migration: it is not possible to say when session migration should start and the time by which it should be completed, as that would require to know where the user is looking at and whether the devices could be seen at the same time.

In this paper we discuss our experience with the evaluation of a user-centric mobility framework. Such framework is built around the concept of Personal Address (PA) [1], i.e., a network address logically associated to the user rather than to a physical device; it accounts for personal mobility, terminal handover and session migration.

We carried out user evaluation in a live demo at a national science exhibition, by asking visitors to compile a short questionnaire after they had tried the demo themselves. We did not limit to gather feedback about our framework, but we also asked more generic questions that was used to figure out what users expect from a pervasive system and how they are willing to interact with it. We think our work may be a reference for whoever would deal with mobility issues in user-centric systems.

The paper is organized as follows. Section II provides a brief overview about mobility, in particular for what concerns session migration. Section III explains the PA concept and the user-centric framework for mobility, while Section IV discusses the current architectural solution. Section V describes how the mobility framework was used to build a Video and Voice over IP application (VVoIP) for user evaluation and Section VI describes the set up of the live demo. User evaluation is discussed thoughtfully in Section VII and final remarks are given in Section VIII. Finally, our conclusions are derived in Section IX.

II. RELATED WORK

Applications establish communication sessions over the network and maintain a status and a context for each of them. The migration of an on-going session requires the transfer of its status/context to another instance running on a different host, therefore this kind of mobility always requires support at the application layer. Some applications have very complex status information and so migration is not a trivial task; thus, this topic has not been considered in the literature as much as terminal mobility [2], [3].

Session migration may be implemented by means of specific middleware, working for all applications. The Adaptive terminal Middleware (AMID) [4] provides an architecture for network monitoring, device discovery and session migration. The middleware scans for devices on each network and makes decisions on the basis of resource availability. The migration architecture requires the user to have a mobile device with him: this device is supposed to follow the user during his movements, it maintains the current context and controls the session for the whole duration; it can either redirect media from the source to the new local device or act as a proxy to deliver media to the current local device, without any update to the source. This last scheme is useful when the new local device is not addressable from the source, e.g., it lies on a local network without a direct Internet connection.

The most recent paradigms for session migration aim at maintaining the same IP address for the whole session duration, VNAT [5] and DIP [6] first introduced this concept. Both of them envision a sort of “loan” of the original IP address coupled with a MIPv6 architecture; the application and transport protocols at the new terminal use the borrowed address, which is translated into a usable real address through specific mechanisms.

Virtual Network Address Translation (VNAT) with MIPv6 [5] relies on the network address translation (NAT) function to map a virtual address (the first used for the session) into a real one (that used at the current host) at both the local and the remote peer.

Delegated IP (DIP) [6] exploits the Return Routability of MIPv6 to redirect packets towards a target node. The original host “delegates” the use of its Home Address to the target node; DIP provides a DIP IP Adaptation Layer (DIAL) and a DIP Transport Adaptation Layer (DTAL) at the target node to receive packets addressed to a third-party from the MIPv6 infrastructure and to deliver them to a local socket.

VNAT and DIP share the risks of using the same address at the transport layer of two different hosts. For example, in VNAT the local host does not keep track of session migrated elsewhere; port number conflicts are possible at the corresponding host whether this latter tried to set up another session before the previous were closed [7] (this is quite likely, as each application usually uses the same port numbers). On the other hand, in DIP the corresponding host cannot reach the local host for the whole duration of the migration because of a route update towards the target node (see [6] for protocol details).

Other issues about VNAT and DIP concern their applicability limited to IPv6 networks. Moreover, VNAT requires its framework to be present in the corresponding node as well and does not manage the simultaneous movement of the two endpoints. On the other hand, DIP only permits one single migration per session; moreover DIP violates the usual division in layers, as it requires the network entities to inspect packets for higher-layer
Two (or more) devices use the same address; port conflicts are possible. The user must keep a device with him.

The Personal Address (PA) [8] enriches the above protocols by bringing the user-centric principles and paradigms into the network as well, pursuing an approach where users have the leading role. Users are the session endpoints whilst devices only act as the physical terminals. To this aim, users are assigned network addresses, which are used by hosts and applications on behalf of the user.

Another approach to session migration is building specific (optimized) frameworks for each application. The Session Initiation Protocol (SIP) [9], chosen for controlling interactive multimedia sessions, supports all aspects of mobility [10].

SIP provides two migration schemes for mid-call mobility (session migration), namely Third Party Call Control and Session Handoff modes [10]. In Third Party Call Control (3PCC), the current terminal transfers the media to a new device, but retains the control of the session until its termination. On the contrary, Session Handoff (SH) transfers the whole session to a new device by notifying the remote peer. SIP also enables advanced features related to session migration, as connection splitting on different terminals [11].

SIP has a very good and complete mobility framework, but this has three main drawbacks: i) it works only for the specific application, ii) it is not integrated with link- and network-layer mechanisms to detect link failures and iii) it requires both peers to implement the framework.

Table I provides a brief comparison of the mechanisms available for session migration.

Table I.

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Layer</th>
<th>Type</th>
<th>Applicability</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMID</td>
<td>Application</td>
<td>Middleware</td>
<td>Generic</td>
<td>Deals with network monitoring, device discovery and session migration. The user must keep a device with him.</td>
</tr>
<tr>
<td>VNAT/MIPv6</td>
<td>Network/Application</td>
<td>Address preserving</td>
<td>Generic</td>
<td>Two (or more) devices use the same address; port conflicts are possible.</td>
</tr>
<tr>
<td>DIP</td>
<td>Network/Application</td>
<td>Address preserving</td>
<td>Generic</td>
<td>Two (or more) devices use the same address; port conflicts are possible. Only one migration is possible.</td>
</tr>
<tr>
<td>PA</td>
<td>Network/Application</td>
<td>Address preserving</td>
<td>Generic</td>
<td>Cross-layer approach. The address is not shared among devices. Requires at least one address per user.</td>
</tr>
<tr>
<td>3PCC</td>
<td>Application</td>
<td>SIP extension</td>
<td>Generic</td>
<td>The original device keeps the control of the session. Session may be adapted to the capability of the new terminal.</td>
</tr>
<tr>
<td>SH</td>
<td>Application</td>
<td>SIP</td>
<td>SIP</td>
<td>Session may be adapted to the capability of the new terminal.</td>
</tr>
</tbody>
</table>

Information (i.e., source and destination ports), and this results in increasing the complexity of the solution.

User evaluation is not taken into account in papers dealing with session migration; however, user preferences should be a leading factor in designing multimedia pervasive systems.

III. A USER-CENTRIC MOBILITY FRAMEWORK

A lot of mechanisms and protocols for mobility are available, but most of them only cope with one specific aspect, mainly handover and terminal mobility. We cannot find a generic and flexible framework suitable for any kind of application.

Apart from the SIP protocol, no example of user-centric approach is known. However, a slight evolution has taken place during the years from a prominent network-centric paradigm to a more recent device-centric approach. Indeed, most of the oldest mechanisms are mainly focused on solving the problem from a network perspective. One solution was to keep invariant the IP address of devices and to deploy mobility infrastructures to trace their position within the network; this avoids maintaining host-specific information in the routing tables for each mobile host, which would not scale for the whole Internet. Anchors, proxies, multicast and end-to-end signaling have been used to this aim [2], [22], [23], [24], [25].

Recently, new approaches have been proposed that hide the changes in network-terminal to the applications without requiring any network infrastructure. We denote them as device-centric just because of this. We briefly discussed two interesting examples of this approach in Section II based on an invariant IP address, namely VNAT and DIP.

However, to fully implement the user-centric vision, the main principles of this paradigm must be brought into the network as well, in order to build communications around the users. That means users should be the session endpoints (sources and/or destinations), at least in principle, whilst devices act as the physical terminals. Such idea was the starting point to derive a general mobility framework at the network layer. Briefly, we assign network identifiers (addresses) to users; these identifiers will then be used by hosts and applications on behalf of the user for networking issues. The basic idea is...
IPv4, which currently lacks addresses for devices, although it would be possible in IPv6. However, to maintain the approach as general as possible, we keep in mind the limitations of IPv4 and think at the PA scheme.

The core of this framework works at the network layer and it deals with both terminal handover and session migration in a uniform way. The main idea is to maintain the same network address for the whole session duration, while the network and/or the device change. Obviously, we need some interaction with the application for handling its context during session migration and thus our framework spans across multiple layers.

A. The concept of Personal Address

We think users may be assigned static and invariant identifiers, likely in the form of Universal Resource Identifiers\(^1\) (personal mobility). User identifiers are then translated in temporary Personal Addresses depending on the underlying network technology.

We define the Personal Address (PA) as “a network identifier dynamically assigned to a user for a specific communication session.” Personal Addresses are exploited to identify users instead of their terminals. Actually, we may use any kind of network identifier (for example, those provided by HIP [27]); until now, we have been focusing on IP addresses in order to deploy our framework in the current Internet.

The PA is specific for each communication session\(^2\); that prevents the risk of having address/port conflicts whether multiple sessions were initiated by the same user at some corresponding node.

The corresponding nodes involved in the session see at any time the same address, independently of the user movements and the devices used. Any migration (handover or session transfer) is transparent to remote applications and these latter are not required any specific functionality. This is one of the main assets of the PA scheme.

Figure 1 depicts the basic idea behind the PA concept. The user is assigned a network identifier (the IP address 1.1.1.1 in this example), this address is used to manage multimedia content (like a VVoIP session) on a small portable device (for example, a handheld), independently of user movements across different networks (dash and dot arrows). The same network identifier continues to be used when the session is transferred to a different device, for example a television with a bigger monitor (dash arrow).

B. The mobility framework

The mobility framework based on the Personal Address accounts for both terminal handover and session migration. A cross-layer approach is the most suitable solution to handle all of these issues efficiently. Our mobility framework mainly works at the network layer, although some operations are still necessary at the application layer to migrate the session context. Figure 2 depicts the architecture of the mobility framework.

The PA Management function retrieves a PA for the current user and makes it available for the application. In practice, this is accomplished by adding the Personal Address to the network interface of the current device (say Terminal 1 in Fig. 2); only one application at a time can bind to it.

The PA must be a topologically independent address, as it does not reflect the current point of attachment to the network. Thus, the network must provide a Delivery function to locate the user and to deliver packets to the current terminal. When the network or the device change, the PA remains the same, but the Delivery function must be updated with the new location.

The Handover task deals with two main issues: movement detection and handover management. It works at

\(^1\)Actually, the user identifier may be a structure including information for different networks (see, for example, Chapter 15 in [26]).

\(^2\)The idea of using a fixed IP for each user is not feasible in IPv4, which currently lacks addresses for devices, although it would be possible in IPv6. However, to maintain the approach as general as possible, we keep in mind the limitations of IPv4 and think at the PA as a dynamic address.
the network layer because the PA is physically configured as a network address of the host; moreover, handover is usually implemented in a more effective way at this layer.

The Migration function moves the user PA and the application context from one terminal to another and updates the Delivery function about the new location; this last task is essentially the same as in terminal handover, thus it can be accomplished by the same mechanism.

Usually, UDP is used to transmit multimedia traffic; however, for the sake of generality, we should also envision a TCP-Migration function whether TCP connections were used (this mainly happens for signaling).

The migration may involve heterogeneous devices or even different implementations of the same application. In order to preserve transparency for the corresponding peer, the network should provide an Adaptation function, which adapts the session to the new device. This function may deal with bandwidth requirements and different device capabilities; for example, for multimedia streams it involves transcoding of codecs, frame rates, aspect ratio, etc.

The concept of PA and the structure of the mobility framework lead to three great advantages with respect to previous works (i.e., VNAT, DIP). First, the device-independent nature of the address enables an arbitrary number of migrations. Second, the presence of a Delivery function in the network also makes it possible to account for simultaneous mobility of both peers. Third, corresponding nodes are completely unaware of any mobility issue.

IV. IMPLEMENTING THE MOBILITY FRAMEWORK

The cross-layer architecture depicted in Fig. 2 allows to split the implementation into two main components, namely core functions common to all applications and application-specific functions.

A. Core functions

The core of our mobility framework is the part which is common for every application. It includes all the functions working at the network layer.

Summing up the main design guidelines discussed in Section III, we need suitable mechanisms to address the following issues:

• finding the user’s current device(s);
• forwarding packets towards the user’s current device(s);
• managing the change in network and/or device at the user side;
• updating the forwarding at the network side when the migration occurs.

Instead of thinking at entirely new mechanisms for the Handover and Delivery functions, we searched the scientific literature for architectural schemes that manage topological-independent network addresses. We found three alternatives: multicast, anycast and Mobile IP.

Multicast [28] provides an architecture to deliver packets to IP addresses (class D) that do not lie on the same network; unfortunately, at present multicast infrastructures are available only within few administrative domains.

Anycast [29] uses the same unicast IP address for multiple hosts, delivering packets only to one of them through standard routing mechanisms. However, routing is known to be slow to converge and the user client would unlikely be allowed to propagate its own routing information.

Mobile IP (MIP) [30] enables mobile nodes to use a fixed network address (the Home Address, HoA) independently of their location. It only requires a minimal infrastructure: one Home Agent (HA), owned by the user himself or some service provider, and optional Foreign Agents (FAs) in local networks for the sake of improving performance (only for IPv4 networks). This protocol registers a dynamic IP address (Care-of Address, CoA) for the Mobile Node (MN) with the Home Agent, so the latter can forward packets addressed to the HoA to the current host location. Moreover, it is transparent for Corresponding Nodes (CNs). MIP includes security mechanisms to prevent most attacks concerning flow redirection and spoofing.

MIP is a suitable solution for our framework, at least at the current implementation stage. In the MIP architecture, packets addressed to a Mobile Node (MN) are routed towards its Home Network, which is the network that the HoA topologically belongs to. As shown in Figure 3, if the MN does not lie in this network, packets are captured by the Home Agent, which answers to ARP Request packets on behalf of the MN with its own MAC address. The HA records the current position of the MN in terms of Care-of Address (CoA), which is the address packets must be sent to. This forwarding is made through tunneling mechanisms. The CoA is either the address of a local Foreign Agent (FA-CoA) or a temporary address assigned to the MN (Co-locate CoA, CoCoA); in both cases, packets finally reach the MN (see [30], [31] for details about MIPv4/6).

The same structure can be used in our mobility framework for the Handover and Delivery functions: MIP clients accomplish the tasks of the former, while the HA acts as the latter. However, we formally consider the HoA assigned to the user, rather than to one device of his; the device is simply a physical mean to use the address and so the HoA can be considered in every respect a Personal Address.

As a matter of fact, MIP was developed for terminal mobility, but its framework does not require the registration to be updated by the same host. We exploit this consideration to update the Delivery function from a different host in case of session migration3. From the HA perspective, this appears as a standard terminal migration, thus packets are redirected to the new terminal. Figure 4 sketches this mechanism; note that the FAs are not mandatory, although they are useful in the IPv4 version to speed up the process of detecting a migration whenever

3 Obviously, the hosts migrating the session must share the same secret material requested by MIP security mechanisms.
it occurs.

The last core function in our framework is TCP-Migration. It is only needed for applications relying on connection-oriented services from the transport layer. We have not still taken into account this issue in our implementation; however, we are currently thinking at splitting the connection at an intermediate agent, like MSOCKS [32]. This approach maintains transparency with respect to third parties (the Corresponding Nodes); moreover, the intermediate agent may be co-located with the HA.

B. Application-specific functions

Four tasks are needed to handle application-specific issues of the PA Management and Migration functions:

- retrieving the Personal Address;
- setting up the Personal Address;
- saving, transferring and restoring the application context;
- removing the Personal Address.

A generic and common protocol may be considered to accomplish the first and third tasks; however, in the current implementation we delegated the application to take care of that. This way, we avoid adding new architectural elements; anyway, the two approaches are substantially equivalent. This issue will be covered in details in Section V.

Adding or removing an IP address to a network interface (the second and fourth tasks) is a trivial task and can be done by the network APIs of the operating system. It is worth noting the four tasks must be triggered by the application in any case.

Finally, we envisioned the presence of an adaptation server (e.g., transcoding). It may be located at the Home Agent, because all traffic is forced to cross this point. Our focus was mainly on the mobility infrastructure, so we did not consider either any solution nor implementation for the Adaptation function.

V. AUTOMATIC SESSION MIGRATION FOR INTERACTIVE MULTIMEDIA SESSIONS

For the purpose of evaluation, we need to select a specific application which exploits the PA mobility framework. Among several alternatives concerning multimedia transmission, we found interactive communications the most challenging and suitable example, as of their hard requirements for real-time operations. Further, to make the whole framework more appealing for user evaluation, we also decided to account for automatic migration by exploiting information about the user position [33].

We selected SIP as the signaling protocol for the interactive multimedia communication framework; thanks to its flexibility, this protocol can easily integrate session control (initialization and migration) and user localization.

This Section describes the localization system and the SIP messages used to implement the application-specific part of the PA mobility framework.

A. User localization

User localization is made by two components: the Localization Server and a localization system.

The Localization Server gathers information by heterogeneous localization sources and computes the user position. In order to abstract from a particular localization system, the Localization Server was designed on top of the SAIL architecture [34], to enable the abstraction and integration of heterogeneous sensors within a common context-aware framework. In SAIL a localization system monitoring a set of mobile devices is abstracted as a set
of logical devices (one for each mobile device) providing their localization information. SAIL also provides a simple way for allowing multi-protocol network access to the data, which becomes useful for integrating the Localization Server with the Personal Address Mobility Framework.

Behind the Localization Server there is the actual localization work. This is done by sensor networks, a low-cost wireless technology that is expected to be largely deployed in the near future. Sensors are tiny devices with limited computing capabilities, integrating hardware for environmental monitoring (typically temperature, brightness, humidity, position, speed, acceleration) and short-range radios; these devices have networking capabilities as well.

Localization establishes which terminal the user is close to; this happens by evaluating whether he is inside the "usage range" (Area of Interest, AoI) of a terminal. Such an estimation of position is quite raw, but it is enough for session migration. To this purpose, fixed sensors (called anchors) are placed around each terminal, whose position is known "a priori"; the user carries with him a mobile sensor.

The mobile sensor, which needs to be localized by the system, periodically emits a beacon packet containing its identifier. As the anchor sensors receive the beacons, they compute the corresponding RSSI and send to the Localization Server all the pairs \(<RSSI, anchor id.>\). The Localization Server accumulates all the pairs and, using a couple of thresholds evaluated during a training phase, estimates the mobile position.

In our testbed the mobile position are obtained by means of a network of MicaZ sensors\(^5\), which operate at the 2.4 GHz ISM frequency band and adopt the IEEE 802.15.4 communication protocol.

B. Automatic migration

Proxy and Registrar servers are used in SIP to locate the user’s current device. We co-locate the HA and these functions in a single element and extend its interface. Personal Addresses are taken from the Home Network address space and dynamically assigned by the Proxy as detailed in the following.

Figure 5 shows the signaling flow for setting up the session and for migrating it from one local terminal (LT1) to another (LT2); we extended the basic SIP signaling (see [9]) to account for migration-specific issues, i.e., retrieving the PA and transferring the session context.

The PA is assigned during SIP registration, but it will only be used when the session starts. There could be objections about the fact the address is assigned and perhaps never used; we argue this is our implementation choice for the sake of simplicity, but other solutions can be easily integrated, as providing extensions to the registration message to get the address when really needed (see, for example, the procedure outlined in [8]).

The registration makes the Proxy aware that the user is "on-line" and his location needs to be tracked in order to know his current device (the Local Terminal, LT). Thus, the user’s Proxy subscribes the location service at the Location Server of the domain where the registration came from (SIP provides SUBSCRIBE/NOTIFICATION messages). We did not explicitly address the mechanism used to find the Location Server for a domain; however, that might happen through standard TXT or SRV resource records; moreover, the domain name could be retrieved by a reverse query for the source IP address of the registration message. After the subscription is completed, the Location Server starts immediately updating the user position and the closest available terminal (LT1 in the example).

Requests of setting up a session coming from Corresponding Nodes (CNs) are forwarded by the Proxy to the current device LT1. Before answering the INVITE message, this terminal adds the PA to its network interface and runs the MIP client registering the PA as the HoA; from now on, the SIP user agent begins using the PA just set up and all signaling and media are routed within the MIP architecture through the HA\(^6\). The same mechanism also applies if the mobile user’s terminal initiates the session; the only difference is that the PA is set up before sending the INVITE message.

When the user moves closer to a new terminal (LT2 in Fig. 5), the Localization Server notifies the Proxy of the change. The latter updates the registration with the Registrar server. The Proxy is stateless, thus it does not know whether there is any active session; nevertheless it sends a REFER message to the previous device LT1. If a session is active on LT1 for the migrating user, this terminal initiates an INVITE/OK/ACK exchange to transfer the current session context to LT2. The INVITE message contains the session description, including the PA to use. During this phase, the MIP client is stopped on LT1 (after the OK is received) and the PA is removed from its network interface; then it is added on LT2 and another MIP instance is started with the same PA (after the ACK message). That updates the location of the PA inside the network; this sequence of operations avoids the duplication of the IP address on the two terminals. Note that the remote peer CN is completely unaware of the migration procedure as the IP address used in the session does not change\(^7\).

VI. THE LIVE DEMO

The live demo was organized at an Italian national science exhibition, named “Science Festival”, held in

\(^4\) The deployment of the localization system requires a training phase, which consists in configuring and calibrating the sensors providing localization information for the AoI. The calibration enables the sensors to recognize when a person equipped with a localization sensor (the mobile sensor) enters or exits the AoI.


\(^6\) SIP provides the current IP address of the remote terminal in the “Contact” field of the headers, thus the CN knows the PA to use after receiving the OK message.

\(^7\) The presence of an adaptation server on the Home Agent would take care of transcoding, if needed. We did not deploy it in our testbed.
Figure 5. SIP signaling for session set-up and migration in the mobility framework.

Genoa on October 23rd – November 1st 2009. The Science Festival\(^8\) is an important Italian dissemination initiative where researchers in different science and technology fields meet a large audience, ranging from business men, to students and families. The Festival saw 200,000 visitors that year: 160,000 people visited exhibitions and laboratories whilst 40,000 people attended conferences, shows and free-access events. Indeed, we only stayed at the Festival two days and got feedback from 101 users.

Visitors of the Science Festival are very heterogeneous and usually do not have in-depth technical knowledge; therefore they are more inclined to give plain and unconditioned reviews of demos and applications. Following these considerations, we decided to organize a live demo showing dynamic networking in action and to get user feedback about the PA framework.

Unskilled people have little or no knowledge at all about networking and related issues. It is also very difficult to let them try networking, as this latter is usually hidden behind applications and services of different nature. To this aim, we built a simple Video and Voice-over-IP (VVoIP) application based on the mobility framework with automatic session migration we have described in Section V. The same software also allows a manual control of the migration; it was already used for quantitative performance measurement in both local and Internet scenarios (see [8]).

The testbed was composed by three parts: the SIP agents (one Proxy server and the clients on each terminal), the localization infrastructure (wireless sensors and one Localization Server) and the mobility infrastructure (one MIP Home Agent, one MIP Foreign Agent and the clients on the mobile user’s terminals). The demo followed the architectural scheme depicted in Figure 6: three terminals were used, one for the corresponding (fixed) user and two for the mobile user. All network elements (terminals and agents) were deployed in the same room, with direct connection among them (i.e., no Internet links); this corresponds to the scenario called “local” in our previous quantitative analysis shown in [8]. Two sensors were put near each terminal and an anchor sensor was tied to the wrist of the mobile user by a strip of velcro.

The users began a VVoIP conference; each user could see himself and the other person in the graphical user interface. This is only a minimal VVoIP application: the main window contains stored profiles and provides options to manage profiles, to set connection parameters and codecs, to start calls; the call window also enables to manage profiles and settings. Two rendering boxes are available in the call window: the big box displays the video of the remote user, the little box plays the video of the local user. Screenshots of the application are given in Figure 7.

The mobile user was then asked to move to and fro between his terminals, so he could evaluate the responsiveness of the automatic session migration (there was no way to separate localization and session migration); the corresponding users saw a freezing image during the migration and could assess the nuisance value of this interruption.

VII. USER EVALUATION

User evaluation was conducted in three steps:

- **Presentation**: Users were presented a brief introduction about the user-centric vision and the VVoIP application they were going to try.

\(^8\)Festival della Scienza, web site: http://www.festivalscienza.eu.
Live demo: Users were invited to try the automatic migration during a video call. We prepared three different locations with a laptop each. Each demo session was attended by two users, the first user made a video call from one location, and the second one moved between the other two locations to test the migration. The roles were inverted.

Assessment: After they had tried the demo, users were asked to compile a questionnaire. The assessment phase was not limited to that issue; indeed, it was also extended to the previous two phases by observing commonly asked questions from users, their difficulties while using the migration service, their comments and suggestions for improvement.

The questionnaire was proposed to potential end-users to assess their interest in automatic session migration and to gather their feeling about the usefulness and applicability of such feature; questions were prepared with the support of a psychologist and took into account background skills, familiarity with technology, personal assessment of the system, social impact of this kind of technology.

The questionnaire was organized in three parts:

First part concerned the user’s profile. We were interested in knowing age, gender, education, work, familiarity with and use of technologies in daily life.

Second part focused on the assessment of the live demo. After they had tried the automatic migration of a video call, we asked users to assess their experience in terms of usability and responsiveness of the migration service.

Last part concerned the investigation of user preferences about physical and ergonomic characteristics of sensors, the possible contexts where the migration may be used and potential issues such as security and privacy.

User’s profile

The questionnaire was filled in by 101 people (48 females, 53 males), aged between 10–69. In the analysis of results we divided the subjects based on their age, as shown in Table II. Most results later on are expressed as percentages and are relative to each of these classes; many questions allowed multiple answers.

The Science Festival especially draws the attention of people with a natural gift and practice for technology, usually the younger generation; moreover, many teachers bring their students to this event to get them in touch with applied sciences and future technologies. For this reason, most people who completed the questionnaire were schools, high schools and university students (69 people); Table III shows the average of years they had spent in education, together with other statistical parameters as standard deviation and minimum and maximum values. The remaining part of the sample was rather heterogeneous in terms of education and employment; they were teachers, employees, professional men, housewives, unemployed people and pensioners.

Regarding the use and familiarity with technology, most of the sample feels skilled with technology and uses several devices every day, without distinction between genders. Evaluation of familiarity with technology is placed on a Likert scale from 1 up to 5, where 5 indicates a great familiarity and 1 no familiarity; moreover, visitors were asked to tick off equipment they usually use on a list of 12 technological devices quite common in everyday life. Table IV analyses the number of devices used and the familiarity with technology in terms of mean value, standard deviation, minimum and maximum value.

Detailed statistics about usage of each of the 12 devices in the list are given in Figure 8, classified according to the age classes identified in Table II. The most commonly
used devices are televisions (98%), mobile phones (97%) and PCs (86%), which are used by almost all people regardless of their age and gender. Other kinds of devices are most suitable to different age ranges: video consoles and MP3 players are used by younger subjects, whilst car stereos and laptops are used by adults. Expensive and niche devices are currently less used, examples are PDAs and laptops are used by adults. Expensive and MP3 players are used by younger subjects, whilst

B. Assessment of the demo

After they had tried the automatic migration of the video call, we asked users their feeling about the application. The main purpose was to check the intuitiveness of the framework, the performance of the underlying network mechanism and the usefulness of the migration feature. The first question was the effort in understanding the migration feature (immediateness of use, i.e. Rapidity), which only means the level of difficulty in learning how to use the migration service (in practice, tying a sensor-wristband) and not technical details. The second question concerned performance, and thus how quick the migration happened (Speed). The following questions were about the usefulness of session migration among multimedia devices: how much the user had liked this feature (Pleasant), their assessment about its usefulness in everyday life (Utility) and how much they would have spent to use it (Value). Users answered these questions on a Likert scale from 1 to 5, where 5 is the more positive and 1 is the more negative opinion. Each score corresponds to a meaning adjective, specific for each question; for example, the judgment about migration usefulness was proposed as follows: “very useful” (5), “useful” (4), “not so useful” (3), “not useful” (2), “harmful” (1). The assessment of the economic value of the feature was proposed in Euros according to the following arbitrary scale: “above 20” (5), “5 up to 20” (4), “less than 5” (3), “nothing. I would only use it whether it were free” (2), “nothing. I would not use it” (1). Mean values for each age group are shown in Table V.

As the results show, the effort to understand the user interface and the migration feature was acceptable, even for older and unskilled people; further, we may note younger generations required less effort, as probably they are friendlier and more used to modern technologies than eldest people, which often are less prone to learn new technologies. The rapidity of migration mainly depends on the Personal Address framework as the delay introduced by media codec in video acquisition and rendering is almost negligible; we got a good score here, thus we can take the quantitative analysis for the local testbed given in [8] as a good benchmark for assessing the effectiveness of session migration.

The second part of the evaluation shows a substantial interest by users towards the demo scenario and their willingness to accept the migration feature in the next future; this feedback motivates our work and future research in this field. Users liked the feature of migrating an interactive video session among devices, they considered the service useful and they would have spent some money for it. A MANOVA [35] analysis was conducted to check if there were differences in the answers by different age groups; no relevant variation has arisen among those groups in assessing usability and suitability of the migration service to the needs and interests of potential users.

Finally, innovation was evaluated by asking users whether they had ever found session migration in any application. Most people (86% of interviewed) considered the migration service innovative, as they had never seen before this functionality. A small percentage (9%) said they had already seen similar application, but oral interviews following the compilation of the questionnaires pointed out that most of them referred to side aspects of the demo, which are not related with session migration, as the use of webcams and VVoIP calls. Finally, few users (about 3%) found the migration service similar to other kinds of functionality: the GPS localization available in the iPhone, the automatic re-tuning to a different frequency providing the same station when the first signal becomes too weak (e.g., when moving out of range) usually found in car stereo systems (AF function

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### TABLE IV.
NUMBER OF USED DEVICES PROPOSED IN THE QUESTIONNAIRE AND FAMILIARITY WITH TECHNOLOGY

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Number of Devices (Av),</th>
<th>Familiarity with Technology (Av)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;14</td>
<td>4.16</td>
<td>4.24</td>
</tr>
<tr>
<td>15–19</td>
<td>3.94</td>
<td>4.14</td>
</tr>
<tr>
<td>20–29</td>
<td>4.13</td>
<td>4.21</td>
</tr>
<tr>
<td>30–50</td>
<td>3.92</td>
<td>4.08</td>
</tr>
<tr>
<td>&gt; 50</td>
<td>3.92</td>
<td>4.08</td>
</tr>
</tbody>
</table>

### TABLE V.
USER ASSESSMENT OF THE MIGRATION FEATURE FOR EACH AGE RANGE

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Rapidity</th>
<th>Speed</th>
<th>Pleasant</th>
<th>Utility</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;14</td>
<td>4.16</td>
<td>4.24</td>
<td>4.76</td>
<td>4.48</td>
<td>4.12</td>
</tr>
<tr>
<td>15–19</td>
<td>3.94</td>
<td>4.14</td>
<td>4.22</td>
<td>3.89</td>
<td>3.97</td>
</tr>
<tr>
<td>20–29</td>
<td>4.13</td>
<td>4.21</td>
<td>4.50</td>
<td>4.00</td>
<td>3.31</td>
</tr>
<tr>
<td>30–50</td>
<td>3.92</td>
<td>4.08</td>
<td>4.46</td>
<td>4.00</td>
<td>3.42</td>
</tr>
<tr>
<td>&gt; 50</td>
<td>3.92</td>
<td>4.08</td>
<td>4.75</td>
<td>4.08</td>
<td>4.08</td>
</tr>
</tbody>
</table>
of the RDS\(^9\) system), the handover mechanism of cellular networks.

C. User preferences

Although the migration framework mostly works at the network layer, it implements a service that directly interacts with the user, thus it is important to keep into account the user’s needs and to involve people in the development phase. Hence the last part of the questionnaire investigates how users perceive our technology and their feeling with related ethical issues; in particular, we were interested in understanding whether they found the migration framework intrusive, whether they were afraid about their privacy to be violated and which kind of sensors they would have been willing to interact with.

Session migration is always related to applications, as each of them has its own context to be transferred; however, the migration is not meaningful for every possible application (a file transfer is a typical example where the migration is not useful), thus it is important to find out for what applications users expect the feature to be available.

We selected a list of session-based networked applications, considering interactive sessions (multimedia, chat), content access (broadcast and on demand media, Internet browsing), entertainment (videogames) and generic work applications. Users checked off those they would find our service most useful (multiple selections were allowed); indeed, our demo falls within the most rated topic. The full classification, in decreasing order of preferences is: “phone calls” (74%), “watching TV” (53%), “listen to music” (49%), “Internet browsing” (40%), “videogames” (38%), “chat” (34%), “office applications” (23%), and “other” (2%).

Figure 9 shows the preferred user applications for each age group; in this case there are significant differences. For example, 80% of users aged under 14 would like to use the migration service to play videogames, whilst the corresponding percentage for the other groups is significantly lower (range 15–19=31%, range 20–29=33%, range 30–50=0%, >50=17%). Note that the youngest people always have higher percentages than other groups; this means they checked off a larger number of items for this question; the only exception is the “office applications” item, as users under 14 are students and are not involved with such activity.

From a technological point of view, many features can be implemented in a easier way on certain devices: writing software for general purpose PCs is much simpler than developing Symbian\(^10\) applications for smartphones or firmware for televisions. Unfortunately, users expect the migration feature on most of their daily equipment: “TVs” (83%), “mobile phones” (71%), “desktop PCs” (67%), “laptop PCs” (51%), “MP3 players” (33%), “stereos” (26%), “fixed phone” (24%), “DVD players” (23%), “PDAs” (20%), “smart phones” (19%), “car stereo” (17%) and “others” (1%). This implies the algorithm must be kept simple enough to be ported on a wide range of different devices. Again, users were allowed multiple selections.

The preferred devices vary with age (see Figure 10): 100% of the oldest users (above 50) checked off television, while 92% of youngest people (under 14) selected the cell phone. Other devices voted by a large number of people are desktops and laptops.

Session migration is a component of pervasive communication. The latter relies on complex frameworks which may be difficult to deploy in certain scenarios \([20]\); however, users may not need pervasive communication everywhere. Indeed, user feedback was quite surprising for us: they mainly expected session migration at home (which is the preferred answer of eldest people), and only in lower percentage everywhere (which is the preferred answer of youngest users). The full classification is: 50% “at home”, 32% “everywhere”, 26% “at school/work”, 15% “in street”, 4% “nowhere” and 2% “other”.


\(^{10}\)The Symbian Fundation, http://www.symbian.org/.

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11 shows the detailed answers for each age group.

As a side effect of automatic session migration, users’ movements have to be tracked and this may concern privacy issues for many people, hence the natural question for users was where they would be willing to be located by sensors. Most users checked off their own home, whilst other options got far less preferences: 60% “at home”, 27% “in street”, 24% “at school/work” and 20% “nowhere”. The large gap among “home” and other options sounds quite strange; perhaps people take privacy for granted in personal environments, i.e., a tracking system working at home keeps all data on private equipment and does not allow anybody to access such information.

Taking into account the behavior according to age, all groups agreed that home is a perfect place to locate sensors, while disagree in the other responses (see Figure 12). People aged 20–29 and 30–50 are less inclined to be located with respect to other groups, people under 14 and above 50 are more willing than others to be also located “in street” and people aged 15–19 have a higher percentage “at school/work” than other groups. This last fact is quite curious as well, as teenagers often care about letting their parents know they are (or are not) at school! Another consideration regards the fact many people above 50 have already left work.

Just to be sure our users were aware of the relationship with current technologies, people who did not like to be located anywhere were asked if they knew cellular systems indeed maintain information about the cell of their phone (and implicitly of their position); everyone said yes to this question and thus we argue people are willing to postpone their qualms about privacy whether they are really interested in the service.

Another issue in pervasive communication is the presence of public, shared and private devices in the environment. That poses security concerns around who is allowed to use what. From the user’s perspective, the problem is twofold: which devices the user would use among those available and whether the user would share his own devices with other people.

The first side of the problem concerns the use of equipment by the user. To this aim, we identified three classes: own devices, devices belonging to people the user knows and public/third parties’ devices. Most people would use their own devices and those of their friends, but few users are interested in other devices; the classification we got from the questionnaire is: own devices (44%), own devices and devices of my friends (43%), all devices (10%), public devices (5%). Note this time only a single answer was allowed.

Figure 13 shows the results for the different groups of users. Only people aged between 20–29 are interested in using public devices; indeed, this group includes university students and young workers which are usually more used to share computers and other devices with their colleagues (at the university, at office); on the other hand, teenagers and elder people are more bound to the concept of personal computers and often do not know features as centralized profiles and authentication management.

The other side of the problem concerns sharing of user’s devices: if the owner is not currently using them,
they may be used by other people to enrich the environment pervasiveness. The result is congruent with the previous question: people are not inclined to share devices with third parties. Indeed, most of them would only let their friends to use their own devices (75%), some people would not lend devices to anyone (10%) and very few users would make them available to everybody (5%). Figure 14 shows a slight trend for older users to share their devices with friends.

Coming back to more technical issue, some questions were devoted to sketch enhancements and guidelines for the future development of personal mobility infrastructures. These questions concerned the interaction of users with session migration, mainly integration of sensors in daily life and alternative forms of control of the migration process.

Sensors represent the most intrusive part of the system, as one of them needs to be carried by the user. Other techniques might be used for localization, but sensor networks are currently low-cost and tiny devices, which are expected to be easily spread in most environments in the near future. As of these characteristics, sensors may be integrated in several objects users usually bring with them, and the main question here is what kind of object the users would like.

We proposed a list of items in the questionnaire; 40% of users would prefer sensors as an object to wear, 37% would like it were integrated in their mobile phone, 18% would bring it as an object apart, 8% would integrate it in an article of clothing, 7% would not like any object, 3% would choose other options. Many differences arose among answers from the different groups (see Figure 15). Users who chose an “object to wear” or “other” specified that it could be a clock.

An automatic migration system must take care of selecting the right device to use among those available; obviously, it needs to account for user preferences and impairments, security requirements, and so on.

Despite of the good logic it can implement, an automatic decision maker may not reflect the current user’s need. Thus, some form of direct user control is needed in addition to the fully autonomic feature. Given the nature of the system (pervasive communication, multiple heterogeneous devices, distributed computation), it is necessary to find the most appropriate way for users to interact with the mobility framework.

Several alternatives were envisioned and users gave their preferences as follows: 38% of users would control migration through a voice command, 26% through a gesture command, 19% would prefer automatic migration, 17% would use the mobile phone to control the session, 7% would like a button on the devices (TV or PC monitor). There are many differences among the different age groups (see Figure 16).

VIII. REMARKS ON THE OUTPUT FROM THE EVALUATION

The results coming from questionnaires, the observation of the user interaction with the service and the
analysis of type and number of errors allowed us to give a positive judgment about usability of the migration service (conclusions are drawn using the ISO 9241 standard [36]). This evaluation takes into account three parameters:

- **Effectiveness**: The level of achievement of the objectives. The first and simplest effectiveness index is the achievement of the objective: a product is effective if it carries out its task. Otherwise, if the objective is not achieved, the effectiveness can be measured in terms of number of operations towards its completion state. The migration service has been evaluated as “effective” because all users achieved the goal in the live demo, i.e. they migrated a video call from one computer to another one, without they were required to take any control action.

- **Efficiency**: The effort required by the user to achieve the goal. The migration service has been evaluated “efficient” because users easily learned how it works and they quickly began to use it.

- **User Satisfaction**: The perceived usefulness of the service by users. The service has been evaluated “useful” by users and they talked positively about the migration concept.

More feedback was collected by analyzing answers, comments and critics from the users during the demo. This information provided us useful indication about aspects that should be taken into account in developing user-centric systems. For example:

- **Security**: Users are interested in security and privacy issues involved in using devices owned by other people.

- **Human-Machine Interface (HMI)**: Many users, especially the youngest, underlined the importance of improving the service interface and physical aspect of sensors; obviously these are minor remarks for our purposes, as our framework works at the network layer and the VoIP application was only developed to set up a live demo, while at the current stage sensors are only prototypes and are far from being a real product. About control of migration, a clear and unique trend does not appear from users; indeed, answers from users suggest that different solutions could be integrated, according to different user profiles and preferences.

Finally, the last remarkable aspect to be considered is the tendency of adult users to perceive the migration service as a futuristic technology, while younger users seem more inclined to use this technology in daily life straightaway.

### IX. Conclusions

In this paper, we have applied the user-centric paradigm to dynamic networking. We have discussed the concept of Personal Address and we have described a cross-layer framework which accounts for different aspects of mobility. This framework exploits a cross-layer architecture, which brings together efficiency at the network layer with flexibility at the application layer. The other important benefit is transparency for unaware corresponding applications.

This paper extends our previous work about this topic by presenting the user evaluation we carried out at a national science exhibition. A live demo was built by using the Personal Address framework for a VoIP application with automatic session migration. SIP was used as the session control protocol at the application layer, MIP implements the mobility framework at the network layer, sensor networks were used for tracking the user position and the SAIL framework was used for the Localization Server; only few extensions to SIP were necessary to account for migration-specific issues at the application layer.

Visitors of the exhibition were invited to try the live demo; evaluation was done by written questionnaires and by direct interview, with the support of a psychologist skilled in this field. Outcomes from the evaluation has given positive feedback about the effectiveness of our framework and outlined general indications for designing pervasive communication systems. To the best of our knowledge, no trials of this kind have been ever carried out before.

Users liked the automatic migration feature and they positively assessed its effectiveness in terms of timeliness and speed. Moreover, they found the application easy to use, that especially thanks to the user-centric approach followed by the architecture design.

As general concerns, users would have expected to keep more control over their sessions, mostly by advanced interaction interfaces as voice and gesture recognition; fully automatic migration was seen as something that may elude what they really mean to do. Automatic migration requires locating and tracking the users, and thus privacy issues must be taken carefully into account before considering applicability of such kind of system in environments other than private (especially home). Finally, there is not a large willingness in sharing devices, although there are significant differences among different age groups.

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### References


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