Mobile Agents for Usage-based Accounting in Wireless Ubiquitous Environments

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***Abstract* — Mobile communications and device miniaturization are enabling pervasive ubiquitous scenarios where a plethora of heterogeneous wireless devices are expected to access both traditional and location-dependent services. Within this usage perspective, the intrinsic limitation in resource availability and the widening market of final users make crucial to enable the usage-based accounting of consumed resources. Usage-based charging not only can represent an important revenue for service providers and network operators but also can force users to a more informed resource consumption and leverage the provisioning of services with differentiated quality levels. The paper claims that the accounting of pervasive services requires extending the fixed Internet infrastructure, where and when needed, with mobility-enabled monitoring, processing, pricing and charging functions. The proposed middleware solution evolves dynamically depending on the mobility patterns of portable client devices and can operate locally to them without requiring continuous connectivity with remote centralized home managers. The paper presents an accounting infrastructure based on the Mobile Agent (MA) technology with an example service of city guide assistance. MAs can effectively support session-dependent usage-based accounting, can install new monitoring and charging behavior dynamically, can maximize locality in the access to monitoring data, and can enable accounting even in case of temporary network partitioning.**

***Index Terms* — Pervasive Computing, Service Management, Usage-based Accounting, Charging, Mobile Agent.**

I. Introduction

TELECOMMUNICATION systems and the Internet are converging towards a pervasive integrated scenario that works with an enlarging set of access devices, even mobile, e.g., palm-sized computers, cellular phones and wireless pagers, to access services anytime and anywhere. Different forms of mobility are possible. Users should connect to the Internet from ubiquitous access points, possibly by preserving their personal preferences and set of subscribed services (Virtual Home Environment). Mobile client devices should either connect to different points of attachment or maintain connectivity at any time during their roaming [1].

In particular, the ubiquitous availability of (either wired or wireless) networked computing environments identify new scenarios for service provision and require new support solutions [2]. On the one hand, service provisioning to portable devices should consider the strict limitations on their hardware/software characteristics and their wide heterogeneity. On the other hand, it is necessary both to provide mobile clients with traditional Internet services designed for the fixed network infrastructure and to develop new classes of services depending on the current client position, typically called location-dependent services.

It starts to be recognized the need for accounting solutions to regulate/limit the excessive resource demand of greedy users and to further stimulate the market of content/service providers, especially in expensive mobile communications environments, such as UMTS [3]. In particular, accounting and charging on a per-usage basis can not only represent an important revenue for providers and network operators but also leverage the provisioning of services with differentiated quality levels. This is particularly crucial in pervasive and ubiquitous service scenarios, typically characterized by strict limitations in resource availability and high cost of the communication medium.

Mobility still increases the challenges to be faced by the design and implementation of accounting systems. Mobility-enabled accounting solutions require location tracking while users roam in global environments and the coordination of remote resources, possibly present in different networks with heterogeneous monitoring mechanisms available. In addition, accounting systems should organize pricing/charging strategies depending on mutual relationships/agreements between different service providers and network operators, on the specific characteristics of the accounted services, and even on previous user actions in other network localities. Moreover, mobility-enabled accounting should be capable of operating independently of possible temporary disconnection and network partitioning.

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The hardware/software limits of several categories of portable devices impose the building of an infrastructure over the fixed Internet to support network connectivity and service access [4]. We claim that this support should account access devices for the resources consumed in any network locality willing to open itself to mobile accessibility. For instance, let us consider a tourist equipped with a wireless portable device who likes to access information about the historical buildings, monuments, restaurants and shops related to the downtown area where she is currently positioned. Already available Web servers over the fixed Internet can provide very detailed multimedia tourist information that should be scaled down to fit the specific bandwidth/visualization capabilities of the used access device. This requires new support functions for the wireless access to fixed servers in a location-dependent way and for adapting contents to device characteristics and user preferences. This novel infrastructure should also monitor and charge tourists for network usage, for accessed service contents, and for the computational resources consumed to downscale the contents.

The paper specifically focuses on solutions for the accounting of wireless access devices in mobility contexts, indicated in the following as *pervasive accounting*. We claim that pervasive accounting requires a dynamic and extensible support infrastructure, capable of evolving during service provisioning depending on client mobility. The accounting infrastructure should be in charge of monitoring, registering, pricing and charging resource consumption locally where mobile users/devices move to, without requiring continuous connectivity with remote and centralized accounting managers. The paper discusses and motivates the suitability of pervasive accounting solutions based on the Mobile Agent (MA) technology to dynamically develop and deploy the accounting infrastructure only when and where needed. MAs can effectively support session-dependent usage-based accounting, can install new monitoring and charging behavior dynamically, can maximize locality in the access to monitoring data, and can enable accounting even in case of temporary network partitioning.

Along these guidelines, we have designed and implemented the **P**ortable device **U**sage-based **P**ervasive **A**ccounting (**PUPA**) infrastructure on top of our mobile agent platform*. On the base of a support layer for monitoring, storage and events, PUPA is organized in terms of MA-based accounting agents that follow client movements into the network. Accounting agents maintain the same location of their mobile users, thus enabling local monitoring, control and registration of resource consumption. PUPA integrates well with our previous research work in network/systems/service management and mobile computing middlewares [4, 5, 6].

* PUPA is built on top of the Secure and Open Mobile Agent (SOMA) system. SOMA code and additional information about the platform are available for download at: `http://lia.deis.unibo.it/Research/SOMA/`

II. ACCOUNTING INFRASTRUCTURES AND CHARGING MODELS

Service provisioning to wireless access devices in mobility contexts forces to tackle several issues, from the identification of resource location and availability to the delivery of service contents to mobile users/terminals with the proper data format and presentation, from the definition of proper pricing/charging schemes to the design and implementation of accounting infrastructures enforcing the desired pricing/charging strategies.

The accounting management area addresses all the issues related to metering, storing and processing information about resource consumption. Metering deals with measuring and collecting resource usage information. Storing maintains metering data on stable storage, either in the locality where information has been collected or in a remote administration site with the additional transport and security issues. While metering and storing involve similar activities in all management applications, the processing phases may greatly vary depending on the specific accounting goals, e.g., access control, auditing, capacity planning, and billing. This paper focuses on accounting for billing purposes in wireless scenarios, where the client location and the resource limitations of access devices strongly affect the service management strategies.

Accounting for billing is closely connected to the dynamic conditions of service provisioning, involving both service providers to manage contents (*content accounting*), and network operators to supply the delivery infrastructure (*transport accounting*). On the one hand, this requires implementing more complex charging models, suitable for scenarios with an ever-increasing need for usage-based faring. On the other hand, the ubiquity of service access impose to take into account the mobile communication environment with its peculiar properties, such as very variable connection availability, high cost of the communication medium, and limited resource availability of the typically used access devices.

The traditional management solutions, spanning from the OSI Common Management Information Protocol (CMIP) [7] to the IETF Simple Network Management Protocol (SNMP) [8], face also accounting aspects, even if they are not specifically designed for accounting management. Accounting in the open Internet requires also some forms of authentication and authorization: IETF and IRTF have established working groups on Authentication Authorization Accounting (AAA) activities to deploy protocols and architectures to provide AAA services for the Internet. The most well known and adopted solutions are Remote Authentication Dial In User Service (RADIUS) and Diameter [9, 10]. These systems mainly represent general-purpose management solutions designed for traditional fixed architectures. They lack specific management functions for both location-aware accounting and mobility-enabled metering of resource consumption.

We have already stated that the adopted charging model deeply influences the accounting strategy. Several charging models have been proposed for the Internet. The most widely adopted are Metered Charging and Fixed Price Charging, while other emerging ones include Packet Charging, Expected Capacity Charging, Edge Pricing, Paris-Metro Charging and Market Based Reservation Charging, described in [11]. The charging strategy choice is tightly influenced by service type and provisioning conditions, and a useful strategy is to adopt hybrid and combined charging methods, dynamically selected on the basis of the requested service, of the user profile and of the access device characteristics. To this purpose, novel design solutions and new implementations from scratch are needed, thus motivating several recent research projects in the field.

The Charging Accounting and Billing proposal, developed within the frame of the MOBIVAS project [12, 13], is an integrated system targeted to support advanced business models for service provisioning in 3G mobile systems. This architecture allows flexible charging and billing by providing functions that adapt to the relationship between the service provider and the operator of the home/visited network. Market Managed Multiservice Internet (M3I) has the goal of enabling Internet resource management on the basis of differentiated charging for multiple levels of service [14]. The Charging and Accounting System integrates Java with SNMP and aims at differently charging different QoS levels, at dynamically supporting tariff modifications and at promptly distributing them to involved users. The Next Generation Internet (NGI) accounting working group specifically focuses on differentiated charging that can be modified during service provisioning: in particular, the NGI architecture for reverse charging enables an ISP to account final users for their received traffic, even if users are currently connected to other ISPs [15, 16]. On the basis of an IPv6 mobility-enabled end-to-end architecture, the Mobility and Differentiated Services in a future IP Network (MobyDick) proposes an AAA Charging infrastructure interfacing the DiffServ architecture with a dedicated Application-Specific Module (ASM); ASM permits to control service access and to account roaming users/devices by adopting solution patterns similar to mobile IP [17, 18].

All above proposals confirm the need for increasing flexibility and dynamicity; they represent a significant evolution for charging and accounting as they recognize the central role of user/device mobility and of the differentiation of service quality levels. However, we claim the need for more radically new accounting management approaches, suitable for facing all the challenging issues raised by wireless mobility. In particular, in the paper we concentrate on central issues such as dynamic support extensibility, operation autonomy with regards to temporarily unreachable managers, session-based accounting independently of client mobility, and also metering of resource consumption in the hosting network due to the dynamic downscale of service content to fit the limited characteristics of access devices.

III. Mobile Agents for Pervasive Accounting

The merging of mobility, limited access devices, wireless communications and the Internet has changed and is going to change both service provisioning and systems management. Traditional solutions for fixed networks do not suit the new scenario where users, devices and even service components can change their location during service provisioning.

Mobile Agents (MAs) can represent a suitable effective technology to face the issues of this extremely dynamic scenario, first of all for their property of *mobility*. MAs can follow the portable device movements to maintain co-locality with the clients they are working for, or can dynamically move close to needed resources and service components, thus preserving locality in operations. In addition, they can maintain the reached execution state and can restore it when continuing their execution at the destination host. This is crucial in keeping track not only of the service session state but also of the resource consumption history of portable devices connecting to/disconnecting from different network localities.

Pervasive accounting stresses *dynamicity*, as the possibility of modifying and extending the support infrastructure by installing/discarding the needed monitoring, pricing and charging behavior, by adapting to evolving requirements at run-time. Dynamic distribution/modification of code and dynamic resource binding are very similar in case of both MAs and the support of portable device accessibility [4].

Service provisioning and accounting in the mobility-enabled Internet call for visibility of the location of client users/devices at provision time. *Location awareness* is crucial to adapt services to the currently available local resources and to enable accounting strategies depending on local conditions and requirements. Location awareness is typical of the MA paradigm that propagates allocation visibility up to the application level, thus simplifying the dynamic adaptation of service quality [19].

Moreover, the possible MA autonomy from clients simplifies dynamic service *personalization*. While following the device movements, MAs can facilitate the tailoring of services to the device profile of characteristics and to the user personal preferences. These tailoring MAs perform client-specific content adaptation operations and should be accounted for their usage of execution resources. For instance, an MA-based infrastructure for service accessibility can face the change of location of access devices by migrating correspondingly the service adaptation logic, even depending on the conditions about resource availability in the new network locality; the same infrastructure should account the clients for their local resource consumption due to content tailoring.

Accounting also stresses *security* issues, to authenticate mobile users/devices, to monitor and register the usage of system resources and to grant secrecy and integrity in communications. The MA research had to face the complex security challenges inherent to the technology to favor the MA adoption. As a side-effect, several state-of-the-art MA systems provide rich security solutions to choose the most suitable security level depending on deployment conditions [20, 21]. MA-based accounting infrastructures can significantly benefit from already available security mechanisms, policies and tools.

Finally, pervasive accounting need *interoperability* to interact, monitor and control the consumption of resources and service components available in the new, statically unknown, localities where the clients move at provision time. To face similar problems of interaction with unknown resources, the MA research has promoted interoperable and standard interfaces. For instance, some MA platforms already provide compliance with CORBA and related standards, such as the OMG Mobile Agent Systems Interoperability Facility (MASIF) and the FIPA specifications [6, 22].

IV. An Ubiquitous Service Scenario: the Downtown Visitor Assistant

A possible scenario, which can be useful to understand the issues related to the accounting of ubiquitous services, is the guided tour of a city with a virtual Downtown Visitor Assistant (DVA). Let us imagine a tourist equipped with a portable device, e.g., a wireless-enabled Personal Digital Assistant (PDA), who would like to receive tourist information about the downtown area where she is currently walking. The tourist can use a standard browser running on her PDA to access the DVA service. DVA is made available from Service Access Points (SAPs) offering Wireless Local Area Networks (W-LAN) connectivity; each SAP covers a single district of the downtown area.

The DVA service should include not only the access to the wired Internet, but also service provisioning with different quality levels and content tailoring to fit the access device capabilities. DVA costs can be modeled as a fixed subscription fee and a usage-based fee, the latter including connection, access mode, service tailoring and finally offered quality level. The connection cost takes into account the consumption of communication resources. The access mode cost distinguishes local and remote information access: local information consists of tourist data about the currently visited district, and is made available by resources hosted in the local W-LAN; remote information relates to other districts and more generally Internet-wide distributed data, which requires the access to service components outside the wireless locality. The quality level cost takes into account the possibility of accessing services with different presentation characteristics, e.g., only text, both text and images, full information with multimedia animations. The tailoring cost finally takes into account the computational resources necessary to downscale the service contents to fit the specific bandwidth/visualization capabilities of the used access device.

During the subscription phase tourists provide personal information and preferences, used to create their user profiles in a globally available directory server. When one tourist enters a W-LAN, her user profile is downloaded and locally exploited to define how to dynamically tailor the service content and to inform the user-specific charging strategy, i.e., by specifying which metering data are relevant and which ones are not. Until the tourist visits the same district, the metering data about resource usage are maintained locally. When the tourist leaves the W-LAN, the data are processed depending on the applied type of charging and sent to a central DVA server for billing purposes. Finally, only when the user communicates her willingness to end the visit (or after a configurable time interval with no service requests from her), the central server puts together and further elaborates the user metering data from the different localities.

V. PUPA Architecture and Implementation Guidelines

PUPA provides network operators, system administrators and service providers with a layered facility infrastructure for usage-based accounting management in pervasive scenarios. The PUPA system operates on top of the Java-based SOMA platform for the design, implementation and deployment of MA services in global, open and untrusted environments, and exploits modeling abstractions and naming services provided by SOMA [6].

Any kind of interconnected system, from simple Intranet LANs to the Internet, can be modeled in PUPA in terms of proper locality abstractions. Any node hosts at least one *place* for MA execution; several places are grouped into *domain* abstractions that correspond to network localities. In each domain, a *default place* is in charge of inter-domain routing functionality and integration with legacy components.

Naming is based on care-of mechanisms to locate mobile agents and currently connected mobile users. Any MA can be traced via its care-of entity (*agent home*) maintained at the place of its first creation. Similarly, any mobile user has her care-of entity (*user home*) at the default place of the domain of her first registration. The default place is in charge of maintaining the master copy of the user profile, as described in the following. The SOMA naming service transparently updates information at the homes of traceable agents at any migration, and homes of traceable users at their connection/disconnection in different domains. For the performance sake, SOMA permits to have also non-traceable agents/users in order not to pay the overhead of location tracking. All (mobile) entities have GUIDs, independent of their current position. MA GUIDs consist of the identifier of the corresponding agent home associated with a number unique in the home locality, thus permitting to identify immediately the agent home, without querying the naming service. User GUIDs are usually at a higher level of abstraction and defined externally to PUPA, e.g., taxpayer codes; associations between PUPA user GUIDs and their homes are maintained in a globally available directory server. In fact, apart from basic identification mechanisms, SOMA integrates a Service Location Protocol-based discovery for resource access within the locality and an LDAP-based directory for the registration of entities, such as profiles, in need of global visibility. Other details about the SOMA-based middleware for mobile computing are presented elsewhere [6].

The PUPA infrastructure consists of two parts: a Metering Layer and a Pervasive Accounting Layer. The former furnishes the accounting mechanisms for the monitoring of resource consumption and for the safe storage of metering data; this layer is the basis of all accounting functions and should be present in every managed host over the fixed network. The latter adopts the MA technology to dynamically enforce flexible accounting policies, by exploiting MA migration to maintain accounting system agents co-located with accounted mobile users.

A. Metering Layer

The PUPA Metering Layer is capable of inspecting and of making visible a wide set of system-level and application-level indicators about resource consumption. At the system level, it gets information on the processes working on local resources and on their usage of the communication infrastructure. For any process, it can report the process identifier and name, the CPU usage (time and percentage, of both the process and the composing threads) and the allocated memory (both physical and virtual). The network metering data includes, for any process, the total number of sent/received UDP packets, of sent/received TCP segments, of TCP connections, and of TCP/UDP packets received with errors. At the application level, the Metering Layer can collect information about all service components accessed from within the Java execution environment. For any active Java thread, it can detect any invocation of a dynamically definable set of methods. Metering data are made visible by the exploitation of Java extensions such as the Java Virtual Machine Profiler Interface and the Java Native Interface, as described in detail in [23].

These raw metering data are processed to concisely quantify the resource consumption and the service usage. For instance, the network-related information is used to determine the consumption of the overall connection bandwidth. The CPU usage and the memory allocation can provide a rough estimate of the computational costs associated with the service downscaling, e.g. when converting an XML file into the corresponding Wireless Markup Language (WML) page. The invocation of specific server methods on one host over the fixed network is investigated to sense the access to specific service content, e.g., when requesting the `getDescription(Manufact id)` method in our DVA service described in the following.

Let us point out that the PUPA Metering Layer is dynamically configurable: system administrators can disable the monitoring of resources that are considered not relevant for the accounting purposes in general, or to the specifically enabled charging policy. This permits to reduce significantly the overhead of the metering functions [23].

Finally, the PUPA Metering Layer locally maintains the monitoring information in stable storage supports; metering data are typically collected off-line by means of the specialized PUPA MAs presented in the next Section.

B. Pervasive Accounting Layer

The Pervasive Accounting Layer exploits the metering one and determines how, where and when to perform accounting management. It is mainly implemented in terms of two types of MAs: Configuration Agents (CAs) and Gathering Agents (GAs).

CAs are in charge of tailoring the service downscale and of specializing the resource monitoring in accordance with the user profile. The user profile, generated during the service subscription, contains information about the user, about the preferred level of quality of service, and about the category of typically used access device. We are currently working on extending PUPA to cleanly separate user preferences and device capabilities in different profiles, respectively user and device ones, to permit the service access of the same user with different categories of devices. The preferred quality and the device type are used both to perform the operations necessary to dynamically adapt the service content and to enable the monitoring of only accounting-relevant resources. Any CA relates to one authenticated user and works as his care-of entity: it is instantiated at the first user access to the DVA service, and it obtains the user profile from the globally available directory; then it follows the user in her movements by carrying her profile with itself. GAs are the entities delegated of collecting accounting data of users at the end of service provisioning. PUPA keeps track of the movements of any traceable user; when the user completes the service session, a GA is sent in the W-LANs where the user has roamed while accessing the service.

To clarify how the PUPA components interoperate and coordinate in a real service scenario, we present them at work in the accounting of the DVA service. We model each district of the downtown, i.e., each W-LAN, with a SOMA domain, where the IEEE 802.11b Service Access Point (SAP) is provided by a SOMA default place and the other tourist information servers in the district correspond to SOMA places. When the tourist T with her wireless PDA enters a new domain, her entrance triggers a sequence of accounting management actions. Firstly, PUPA ascertains whether T already has a currently open accounting session; to this purpose, the system controls whether T has previously visited another district/domain. If this is the first access to the service, SAP interrogates the centralized directory server to obtain the user profile and then associates the tourist with a newly instantiated CA. Otherwise, PUPA triggers the migration of the previously instantiated CA for that user from the last visited district/domain. In the worst case of network partitioning, when the already instantiated CA cannot reach the new domain, PUPA instantiates a brand new CA for the user.

To avoid CA proliferation, when a CA is inactive for a defined amount of time, it automatically terminates its execution.

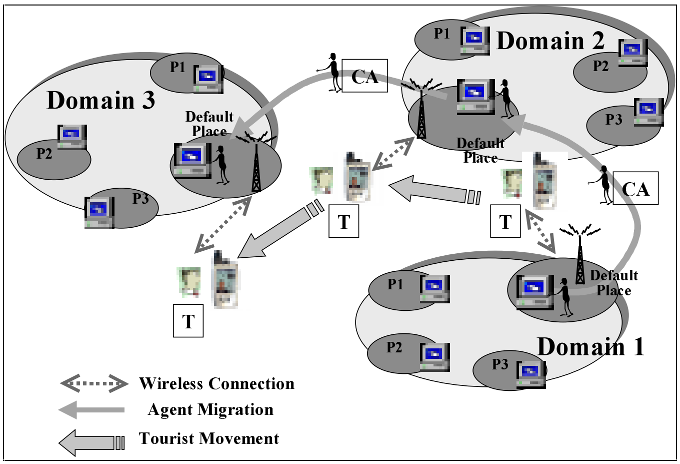

Fig.1 – Configuration Phase

At the end of the guided visit, PUPA instantiates a user-specific GA and sends it in the visited districts to gather the data about the resource usage locally performed by the tourist during the tour. Local service usage data are then processed and summarized to create a global user-specific report for usage-based charging; only at that moment, the user-specific pricing strategies are applied to the accounting data to obtain the final billing.

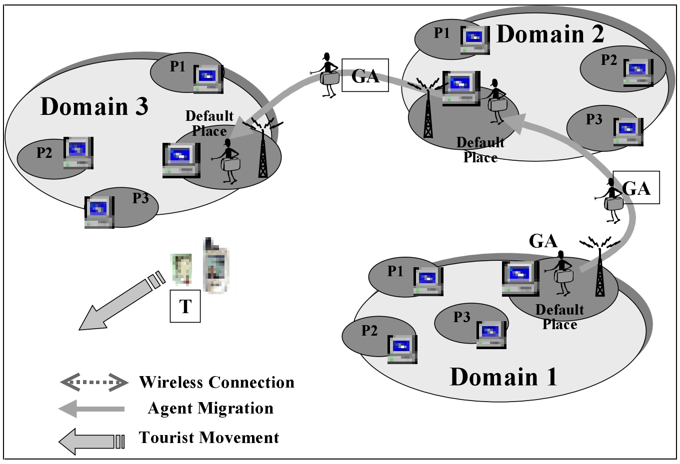

Fig.2 – Gathering Phase

VI. Conclusions and On-going Work

The Internet is likely to offer a pervasive service environment and this requires extending the fixed network infrastructure to support service accessibility to mobile users and portable devices when and where needed. In this context, effective solutions for usage-based accounting are crucial to force a fair resource consumption and to leverage the market of services with differentiated quality. The paper shows how the accounting of portable client devices with wireless connectivity and limited hardware/software characteristics can benefit from highly dynamic support infrastructures that exploit mobile code programming paradigms, and in particular the MA technology.

The first encouraging results obtained in applying PUPA to the downtown visitor assistant service are stimulating further work to produce a usable and complete pervasive accounting system. Issues currently under investigation include non-repudiation aspects and mobile ad-hoc styles of interaction. From the security point of view, PUPA already exploits secure communications channels and encrypted storage for accounting data. However, additional work is necessary to guarantee non-repudiability of resource usage and to establish differentiated trust levels between users and accounting components, so to reduce the overhead of security mechanisms in trusted deployment environments. In addition, we are extending our solution to include scenarios where the service is cooperatively provided by peer portable devices composing a proximity-based ad-hoc network, without exploiting an infrastructure of service access points. This significantly changes the perspective and imposes to face additional challenges, such as how to measure resource consumption on limited heterogeneous access devices and where to store/process accounting data.

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