Agent-based Virtual Home Environment: Concept and Performance Aspects

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Abstract

As a contribution of the ACTS CAMELEON project to the VHE (Virtual Home Environment) concept of UMTS (Universal Mobile Telecommunication System) this paper covers the usage of mobile agent technology in future mobile communication systems. Therefore special emphasis is on the identification of components realisable as mobile agents for the provision and delivery of personalised services across network and terminal boundaries with the *same look and feel* (Virtual Home Environment). Typical scenarios are shown dealing with service subscription, service access and service configuration. To evaluate the scenarios a mathematical model has been defined. Within this model and based on a detailed analysis of the involved protocols results showing the possible benefits and trade-offs of agent migration, messaging and remote invocation are presented.

Keywords: Virtual Home Environment (VHE), Universal Mobile Telecommunication System (UMTS), Mobile Agent Technology (MAT), Subscription, Service Configuration, Intelligent Network (IN)

1 Introduction

The Universal Mobile Telecommunication System (UMTS) [Rap-95] being standardised by ETSI [BL-30] [TS-22], will enforce and improve future mobile systems. UMTS will provide a set of new services to the user and has many new capabilities. Some of the most important key principles of UMTS are the support of Quality of Service (QoS), the Personal Communication Support (PCS) to enhance the personal mobility with respect to advanced reachability control and the Virtual Home Environment (VHE) – the most important key principle from a user's point of view. The VHE will permit "service mobility" or "service roaming" for the user which means that users take their subscribed and customised services with them while they are roaming. On the one hand, this requires the adaptation of management interfaces. On the other hand, it must be guaranteed that the capabilities of any available terminal within any accessed network are sufficient to perform the services of a registered user. During the registration procedure, the VHE will enable a visited network to obtain information about the user's service provider as well as other information, such as the user's personalised service profile and the identification of service capabilities needed for the execution of SP (Service Provider) specific services.

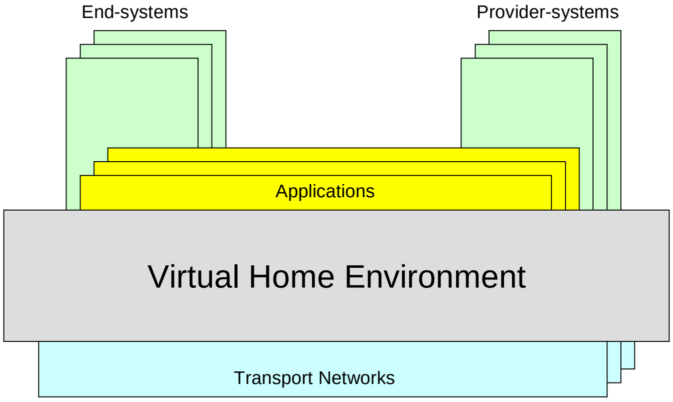

Figure 1: Virtual Home Environment

The VHE can be seen as a (middleware) layer which hides from the user the concrete network (capabilities) and differences in user and provider systems capabilities (see Figure 1). The realisation of such a VHE environment will be discussed later.

Collectively, these principles will enable the provision of services and information ***"anywhere, anytime and in any form".*** Basically, UMTS will be developed as an evolutionary environment. This implies a modular approach in defining the network parts, which is in line with the recommendation of "Global Multi-Media“ [BL-30].

Taking into account that the UMTS environment should enable an open and particularly dynamic market of services, with multiple service and network providers as well as various end systems involved in service implementation, the realisation of the VHE concept represents a challenging task. The following list describes aspects that have to be considered for the selection of appropriate middleware and service infrastructure solutions:

- Service intelligence may be placed inside the network (within the Service Control and Mobility Management Platform (SC&MMP)) or outside the network (i.e. within the Universal Service Identification Module (USIM) of the end system).
- In order to cope with the diversity of end systems (due to personal mobility support), QoS variations of different access networks (due to terminal mobility support), service adaptation is required, including media conversion.
- Since UMTS is considered to be an evolvable system, enhancements regarding the intelligence of service control during service execution should be possible.
- The dynamic subscription of new 3rd party services should be possible.

Based on standardisation results a UMTS environment can be derived. It consists of a terminal, the radio access network (AN), the service control and mobility management platform (SC&MMP) and the 3rd party service provider. Figure 2 outlines the described environment. The terminal component will enable the user to register and to present services to the user. User identification and authentication will be handled by the UMTS Subscriber Identity Module (USIM). The network access of the terminal will be managed by the access network. Fixed or mobile terminals will be linked by the AN to the SC&MMP. The SC&MMP contains the service logic and is responsible for the mobility management (see below). Third party service providers support supplementary services. A 3rd party SP will have a connection to one or more SC&MMPs. It will not have its own mobility management facilities.

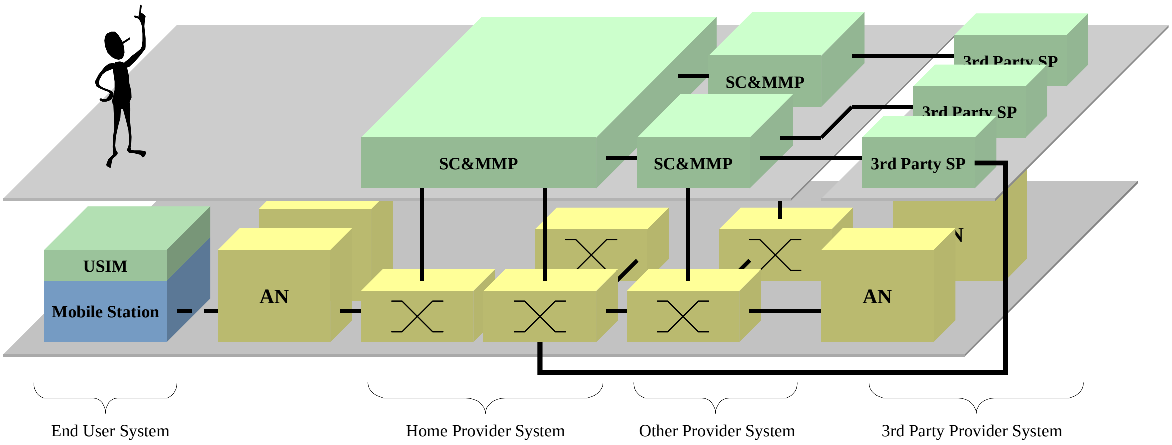

Figure 2: Main Components of a 3rd Generation Mobile Communication System

In the face of the current evolution of second generation mobile systems, driven by the integration of IN architectural principles into these systems, the service control and mobility management platform (SC&MMP) of third generation systems will be natively based on IN concepts. In this context, IN functionality is used to support authentication, mobility management as well as service control by means of dedicated Service Control/Data Functions. This means that the traditional Home Location Register (HLR) and Visitor Location Register (VLR) functionality is implemented by dedicated IN Service Control Points (SCP) which are accessible by the Mobile Switching Centers (MSCs). Furthermore the MSCs are enhanced to provide IN Service Switching Point (SSP) capabilities as already done in the CAMEL architecture [CAMEL].

On the user's side, the so called user equipment consists of the UMTS Subscriber Identity Module (USIM) and the Mobile Station (MS). The USIM contains the user's identification and authentication data and permits access to subscribed UMTS services. This data is stored on an IC or SIM card [GEMPLUS] respectively. Via this card, the support of UMTS as well as the UPT phase 2 registration will be permitted [UPT].

2 Mobile Agents in 3rd Generation Mobile Communication Systems

In the previous section the general UMTS facilities were described. Taking into account the UMTS architecture and the facilities of the MAT, a new figure is emerging (cf. Figure 3). Instead of the SC&MMP on top of the hardware (cf. Figure 2), a middleware layer is introduced. This middleware consists of the Distributed Agent Environment (DAE), e.g. Grasshopper [IKV], Voyager, etc. which are built on top of a Distributed Processing Environment (DPE), e.g. CORBA [OMG-95], and is spanning all potential end user systems and provider systems. The middleware enables all involved system nodes to provide corresponding agent environments, which enable the downloading/migration of mobile agents. These agents contain intelligence related to mobility management and service control (e.g. VHE control) as well as end user applications between the involved system nodes, including the mobile stations. Taking into account the possible openness and heterogeneity of the envisaged target UMTS environment, involving various end (user) systems, provider systems, 3rd party provider systems, etc., it is important to make use of a standardised, i.e. OMG MASIF [Breu-98] conformant, mobile agent platforms, which enable basic interoperability between agent environments of different types/vendors.

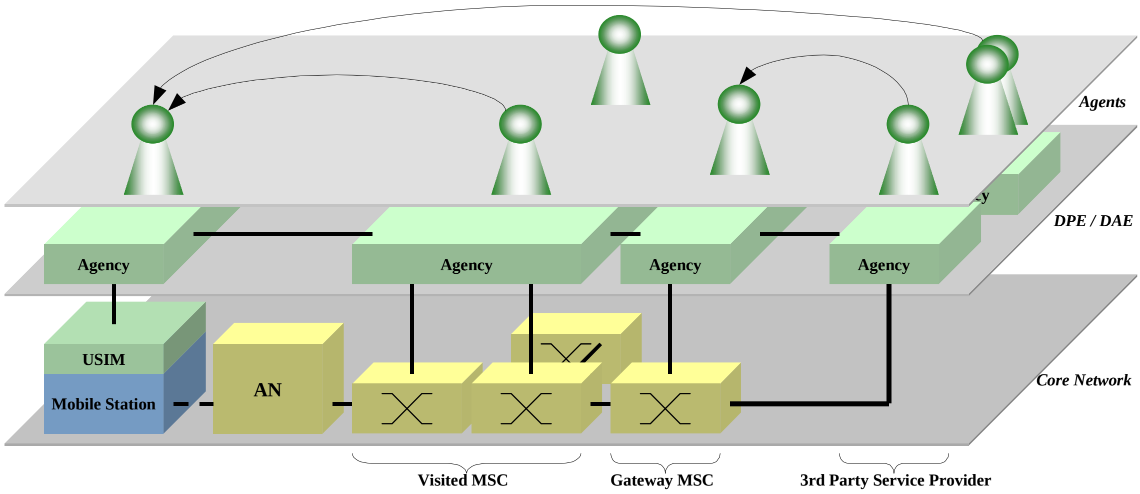

Figure 3: Distributed Agent Environment spanning across UMTS End-user and Provider Systems

Based on the basic requirements to UMTS (cf. section 1), a set of specific components can be identified which are necessary inside a UMTS network. On the user's side the most important part is the VHE. Because UMTS supports a wide range of different terminals it is necessary that the terminal contains a special component. This component has to interact with the communication environment at which the terminal is registered. Such a terminal component has to be able to inform the visited network about its capabilities and characteristics. The UMTS will offer the subscription of various services from different service providers as well as the service subscription from 3rd party SPs. This makes the existence of a special provider component necessary that manages the available services. Such a provider component contains the logic and will act as a trader to give access to the services of the current domain. The provider agent can be seen as an SC&MMP replacement. Taking into account that UMTS is an evolutionary concept that comes from GSM various well defined agent entities can be identified to implement an agent based UMTS:

- a VHE-agent realises the VHE concept,
- a Service Agent (SA) represents a provided service,
- a Terminal Agent (TA) allows the terminal to inform the provider system about its capabilities, and
- a Provider Agent (PA) realises a trader within the provider system, which manages all supported services (SA), i.e. maintains an overview of all available services within the provider domain

For 3rd generation mobile systems, the VHE is one of the most important issues to be realised as a mobile agent. The VHE will enable individually subscribed and customised services to follow their associated users wherever they roam to. The VHE-agent will follow the user to the domains to which the user is roaming. At every domain the VHE-agent will provide the user's subscribed services and its configurations.

Projecting these considerations onto upcoming mobile communication systems, it seems interesting to consider the introduction of agencies within the mobile stations (USIM) and the SC&MMP (i.e. the Mobile Switching Centers modelled as IN Service Switching and Control Points) in order to enable a dynamic distribution of mobility management [DUET][Ram-95] and service control intelligence. The principle idea is to allow service intelligence:

- to be downloaded dynamically from the mobile station into the (visited) provider system;
- to be downloaded dynamically from the (visited) provider system onto the mobile station;
- to be distributed within one provider system at the most appropriate location, e.g. an MSC serving the mobile user; and
- to be distributed between different provider systems.

Hence, end systems (through the USIM) can take an active part in mobility management and service control. Traditionally, subscriber profiles, i.e. HLR entries, containing service-related control information, have been copied within and among the provider systems (into the VLRs), thus they follow the users in order to optimise service provision. Mobile agent technology can be regarded to provide a unified framework for the implementation of mobile user profiles and service logic through mobile agents following the users within one provider network and even between different provider networks. The vision is to replace the HLR and VLRs completely by mobile VHE agents, which roam between the interconnected MSCs equipped with agencies. Furthermore, as an option enabled by means of the USIM, the VHE agent may be placed on the mobile station, i.e. outside the network, and may be injected into another provider domain from the mobile station. Finally, mobile station based service agents may be injected temporarily into the network when the mobile station is going to disconnect for a longer period of time. Thereby, user-related service agents will keep the ability to perform their tasks within a provider agency.

The Provider Agent (PA), which resides within every provider domain, contains the knowledge of all services provided by this domain. In a very primitive case, the PA is a database. But consequently, the PA can be designed as a trader respective as a MAFFinder [MASIF]. The provider agent will be the initial contact point of the VHE agent after the user has roamed to a new domain. The provider agent should be designed as a stationary agent, as migration of this agent is not necessary.

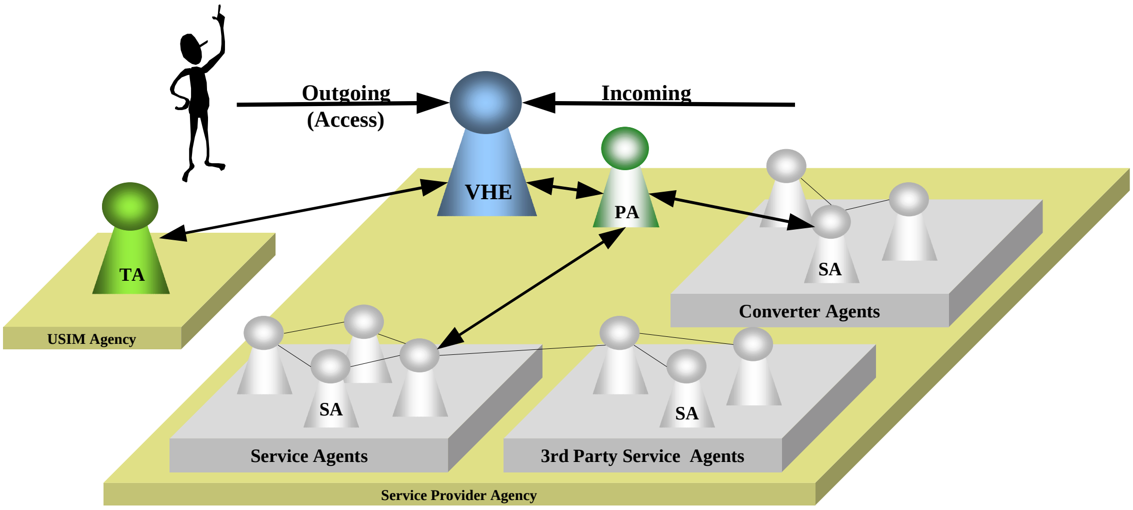

Figure 4: Basic Agent Relationships

A service itself is also represented by an agent, i.e. the Service Agent (SA). The SAs are located within the provider domain, at the 3rd party service provider domains or at user's terminal. A special group of service agents are so called Converter Agents (CA) at the provider agency. They are responsible for converting incoming and outgoing calls dependent on user and terminal requirements. This allows the support of services on terminals which can't originally present the service such as reading out a fax or e-mail on a normal telephone. The knowledge of the terminal capabilities will be maintained by the Terminal Agent (TA). Figure 4 shows the different types of agents as well as their communication relationships.

Taking all the pieces together, it is possible to create a more detailed picture of an agent-based UMTS system. Within the agencies of the mobile stations, i.e. USIMs, we may find different agent places for terminal agents (e.g. a mobility management place), VHE and related service support agents (e.g. a VHE Place), and one place for local user application agents (e.g. Local Service Place). Concerning the usage of 3rd party services, further study is needed of whether separate agencies are required for arbitrary 3rd party provider services (which could be dynamically downloaded into the end systems at subscription time) or just one or more places within one single agency are needed. The agencies within the provider systems, i.e. the MSCs, are featuring corresponding places, e.g. for visiting terminal agents, a user's VHE and mobile service agents, provider specific service agents, as well as any adapter/support agents. Finally, 3rd party service provider systems may be equipped with corresponding agencies related to the services they offer. By definition, these agencies belong to separate regions. However, it has to be stressed that a 3rd party service provider does not necessarily know that the user is using a mobile station. That means that for 3rd party service providers there is basically no difference between mobile and fixed users. Mobile service agents will be sent to and received from remote systems comprising agencies. As mentioned above, different 3rd party service providers may use different agent technologies, thereby requiring the use of different agencies. These could be downloaded at subscription time.

The support for delivering mobile 3rd party service agents to mobile stations has to be supported by the service provider. Hence an MSC may provide an "Agent Mailbox", representing some kind of specialised resource function, allowing mobile service agents on their way between the mobile station (i.e. USIM) and potential 3rd party service providers to be temporarily stored within the provider system, in case the mobile station is not reachable.

3 Virtual Home Environment based on Mobile Agents

The VHE-agent follows the user to the provider domain to which he roams. This agent can be injected from several sources to the provider system, in which a combination of all these options (see below) will be envisaged. This allows an optimal availability of the VHE-agent, independent of the provided capabilities of the service provider to which the user has roamed. The options to store the VHE-agent are:

- The VHE-agent will migrate from the provider domain the user comes from to the provider domain the user is roaming to,
- A major copy of the VHE-agent is stored within the home service provider domain. Whenever the user roams to a new provider domain, a copy of the VHE-agent will migrate to this domain. This scenario is comparable to the HLR-VLR concept known from 2nd generation mobile systems.
- The VHE-agent is stored on the terminal agency or on the SIM card. The VHE-agent will migrate from the terminal agency to the provider agency when the user has roamed to a new domain.

Based on the general architectural considerations given in the previous section, we will now look at the interworking of mobile agents for the provision of VHE capabilities. Therefore a special remark is on the service subscription and the service customisation. It will be assumed that the VHE contains a subscription component which enables users to manage their subscription.

3.1 Service Subscription

As previously mentioned the VHE will provide the user service environment independent of his current location and independent of the provider at which the user is registered. That means that a user's services will be available in various networks the user has roamed to. Furthermore the user will be able to subscribe and to use services from various service providers in a UMTS environment. This makes it necessary, that the user can subscribe to new services, dynamically.

The dynamic subscription implies a special facility inside the VHE. This subscription component must give the user the possibility to subscribe to and to unsubscribe services. Therefore it is necessary that the subscription component interacts with the provider to get an updated list of available services of this provider. But this is a substantial problem. Various providers will offer many different services with different service features and capabilities. The subscription component has to present the whole set of provided services to the user. Hence different ways of information retrieval are possible:

- during the registration procedure (after the user has roamed to a new provider) the subscription component will request the provider to get information about provided services
- a further procedure is based on the method described above. Whenever the user has roamed to a new provider the current provided services will be concatenated to the service list which is stored by the VHE.
- a new component called "Roaming Broker" [MARINE] exists inside the network which allows to get information from other service providers. Here the subscription component contacts the roaming broker. The roaming broker contacts the connected service providers to get the requested information about provided services. This information will be collected and returned to the subscription component where it can be presented to the user.

All these described methods are face with some problems. The major one is that the user now has to decide which service with which service features he wants to use. Therefore he has to have a huge knowledge about very specialised service features which will be provided by different service providers. This is not practical and would not be accepted be the users. An alternative can be the abstract description of services through the user. Hence the user specifies his requests to a service he wants to subscribe to in an abstract manner.

For example: The user wants to subscribe to a video conference service. From a user's point of view only a few parameters are really important. The user wants to specify that a video stream can be sent and received and a voice connection is provided. All other information, possibly supported by the providers, like the image resolution or the used video codec etc. are not really relevant for the user. Another important fact in a UMTS environment is, that the user can be registered at different terminal during two sessions, so that the presentation capabilities of the terminal can vary. Normally, the user would need more than one subscription for the same service so that it can be presented at different terminals. Furthermore, the user would need detailed knowledge about presentation capabilities of the terminal currently used. This is not applicable in a future telecommunication system. Rather the underlying system has to decide which service with which capabilities can be provided. But which pieces of information are necessary for the system to enable a subscription of any possible service?

Basic parameters were identified which consist of communication media, communication mode and communication direction. Additional parameters are QoS, information coding, communication bearer and communication protocol. The communication media specifies the media type which will be used. Their identified values are:

- Voice, e.g. ISDN telephony,
- Text, e.g. electronic mail,
- Image, e.g. picture of the day,
- Video, e.g. MPEG movies,
- Audio, e.g. music,
- File, e.g. binary file transfer, and
- Audio+Video, e.g. video conferences a defined media type of the incoming call.

Applying this media attribute allows the specification of any possible media types of a communication relationship. In a second step the communication mode attribute allows to specify the conversational or store & forward communication relationship. The conversational mode will be applied to a full duplex communication (synchronous) relationship such as telephony or video conference. The store & forward mode or half duplex communication (asynchronous) relationship will be used to specify a fax or electronic mail communication. This communication mode attribute characterises a non time critical communication. The communication direction specifies the direction of information flow. Three possible values were identified. These are the “source” value which means that the information is only outgoing from the sender, e.g. pager information, the “sink” value specifies that the service only receives information without sending active responses and the “sink-source” value specifies that there is an information flow between sender and receiver. Now any possible services can be described by the user by specifying these attributes inside the subscription component.

Normally, these introduced subscription parameters are sufficient for a normal service subscription. Nevertheless, some additional subscription attributes can be important to allow a more detailed and more specialised service subscription. The QoS attribute allows the description of a required quality of service based on parameters like: costs, bandwidth, delay and jitter. The user can take influence on the QoS by setting up his minimal requirements to the service. The information coding, communication bearer and communication protocol attributes will enable the user to specify a specific media codec, a bearer which has to be used and the protocol which shall be applied. But it has to be stressed, that these parameters strongly restrict the availability of services and their presentation at different terminals.

The specified subscription parameters will be stored in a service profile which is part of the subscription component.

3.2 Service Access

In the previous section the subscription was described in an abstract manner. This section will answer the question, how a service can now be subscribed and used. The VHE and its realisation as a mobile agent follows the user through the network while he is roaming. The subscription component which stores a user’s subscription is part of the VHE. This implies that the abstract service subscription is present at the provider where the user has roamed. After the registration of the user at the new provider, the VHE will try to get a reference to service agents which correspond to a user’s subscription. Therefore the VHE-agent will contact the provider agent. The provider agent has to provide a subscription interface to process the VHE request. The provider agent which has knowledge about all services provided by the provider will try to find a service agent which corresponds to the abstract service description. The provider agent will return a reference to an existing service agent if it could find a service agent that matches the service description. If no service agent fits to the service description, the provider agent will try to find a corresponding service agent at different service providers. Therefore the provider agent has various possibilities (cf. Figure 5):

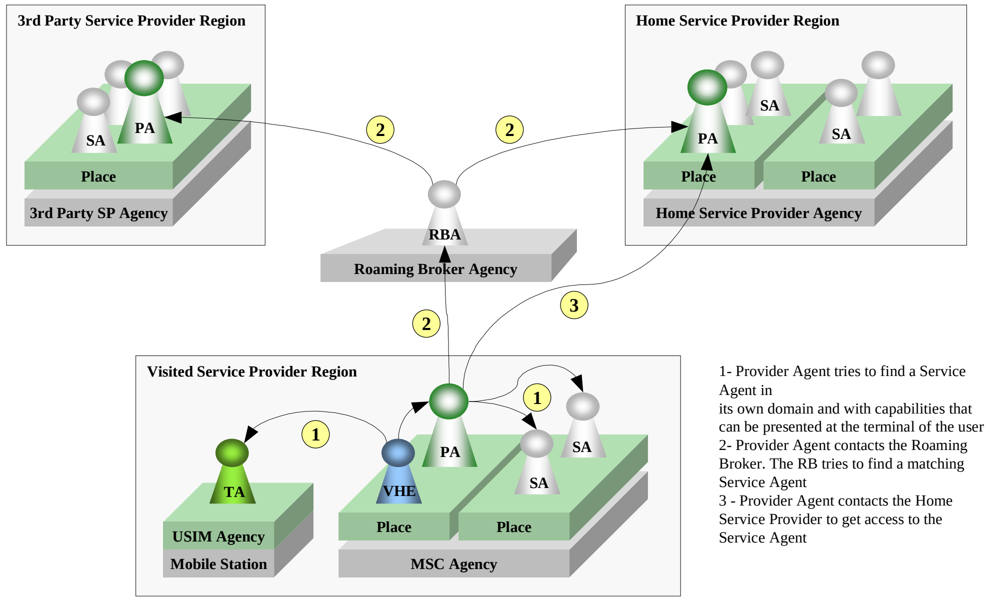

Figure 5: Service Access Strategies

- If the current service provider has contracts with other service providers, it can contacts these service providers to request help,
- If a roaming broker exists inside the network, the service request can be forwarded to the roaming broker by the current provider agent. Now the roaming broker will contact the service providers which are associated to get a reference to a corresponding service agent,
- The service profile stores the home service provider of a requested service as part of the service description. This home service provider can now be contacted to get a reference to the service agent.

If a service agent was found at a different service provider then two service access strategies are possible:

1. The service agent will be downloaded into the current service provider domain. Therefore a copy of the found service agent migrates to the service provider domain at which the user is registered. In this case it can be very useful to know a user's communication behaviour to optimise the network traffic and to protect the network from unused service agent migrations. What does it mean? Most users are using only a small set of services very often and on a regular basis. These services should be available to the user at all times. This means that these services should be downloaded automatically to the new service provider domain when the user has roamed. A service request is not necessary to initiate the download. Other not so often used services should be downloaded only when a service is requested through the user or a called party is occurred.
2. The service agent will be used remotely. Especially for performance and security reasons this option is interesting. Many service agents can be very huge. A download can take a long time and would overload the network, unnecessarily.

In order to choose the best strategy performance analysis for some scenarios are necessary. In section 4 some significant results of a performance evaluation are presented which consider the possible options for the placement and employment of the agents involved in the corresponding scenarios.

3.3 Service Configuration

After the subscription, the user will be able to configure and to customise the new subscribed service. For this purpose, it is necessary to download a new special kind of agent – the user interface agent (UIA). This agent will be responsible for the presentation of the service agent at a user's terminal. The UIA provides terminal dependent service presentation capabilities. This implies, that there can exist many UIAs for the presentation of the same service for terminals with different capabilities.

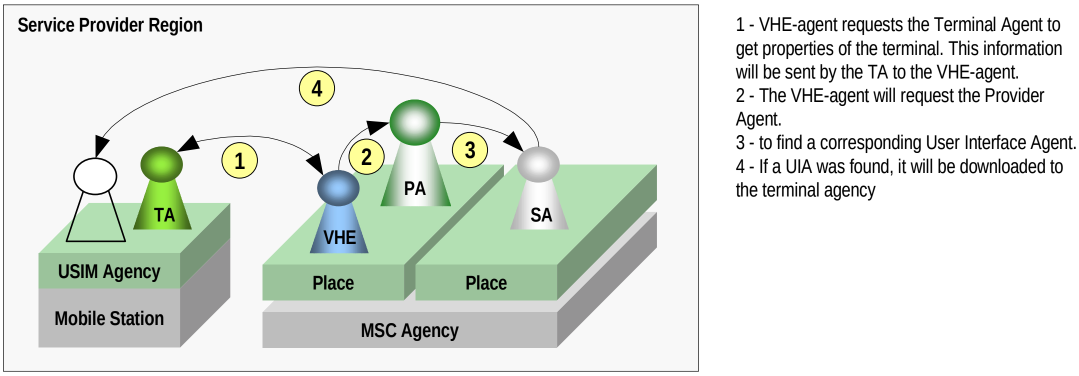

Figure 6: UIA Selection Procedure

The VHE-agent will make the decision which UIA has to be downloaded to the terminal (cf. Figure 6). Therefore the VHE-agent will contact the terminal agent (TA). The terminal agent resides on the agency of the terminal, i.e. a mobile station. This terminal agent is device dependent which means that it contains special technical information about the terminal, e.g. screen resolution, voice quality parameters etc. The VHE-agent will request the TA to get this information. The returned values will now be used by the VHE-agent to find a corresponding UIA. In principle the service subscription procedure will be applied again to locate the UIA (cf. section 3.1).

As mentioned above the VHE-agent contains beside the service subscription list, further user customisable service parameters. These parameters will be stored in the service profile. They will be used to configure the service agent after its subscription. Which service parameters are customisable depends on the specific service. This implies that the specific service parameters will be stored with an association to the corresponding service. Nevertheless there exist some common service features, i.e. language selection, which can be stored in a separate part of the service profile. A possible structure of the service profile is given in Figure 7:

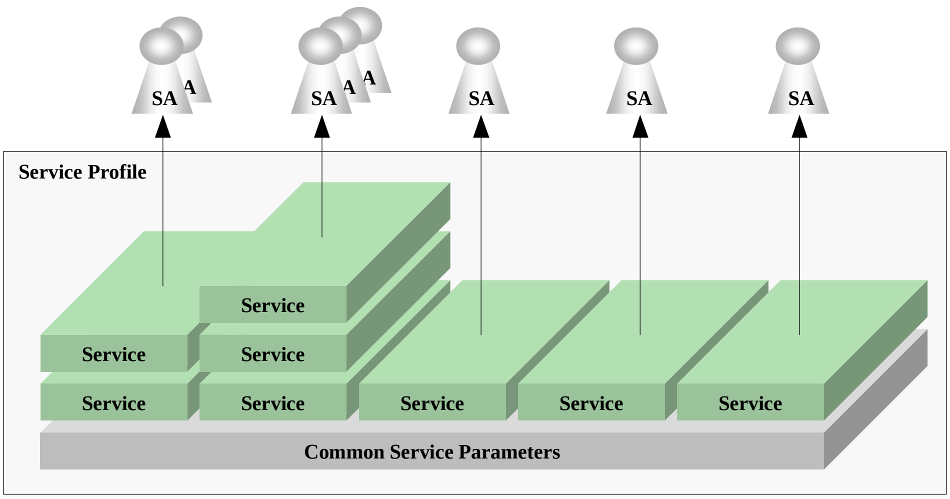

Figure 7: Service Profile

As known from IN, services can be built of service features. Similar to the IN service features, agent based services can be built in the same way. That means, that sets of agents build a service. Inside the service profile such a compound service can be represented by hierarchical service profile entries (cf. Figure 7).

4 Performance Evaluation

As mentioned in previous sections the introduction of the Mobile Agent Technology to UMTS necessitates some enhancements of the existing network components. As UMTS is an evolutionary concept, which means that it should benefit from the research activities and experiences made within GSM, it is interesting to ask, in how far current network components should be replaced or enhanced to new interfaces. In Phase 2+ of GSM the CAMEL Technology, based on IN concepts, is being introduced. Therefore it is reasonable to keep the existing functionality of CAMEL, but to implement different interfaces corresponding to the MAT.

After the description of a general agent based approach for providing VHE in UMTS in the previous sections, for our performance analysis we have defined a concrete architecture with places and dedicated agents. This is the assumption for obtaining realistic evaluation results considering the protocols of the agent system as well as those of the underlying networks which are described in the following.

The overall architecture of UMTS integrating the MAT with the corresponding agents is illustrated in figure 8. It contains the network components with MSC (Mobile Switching Center) functionality known from the GSM architecture like mobility management, bearer control, etc. However, the MSC in UMTS will be more integrated than in GSM. It should manage different access networks, e.g., existing GSM BSS (Base Station Subsystem) and UMTS RAN (Radio Access Network). The transport technology for Signalling and Data over the I_u interface is expected to be ATM (Asynchronous Transfer Mode). The core network will be based on ATM technology as well. These integrated MSCs called UMSCs will be connected to one or more SCPs (Service Control Point), which are able to provide CAMEL functionality.

The user will be equipped with a terminal which contains the required components managing the radio interface MT (Mobile Termination) and indicating the information TE (Terminal Equipment). As mentioned before, for the integration of MAT into the UMTS the SSPs (Service Switching Point) and SCPs of the UMSCs should be enhanced by additional interfaces. Hereby, the functionality of SCFs (Service Control Function) and SDFs (Service Data Function) are partially merged together for providing a distributed architecture. These combined SCFs and SDFs are called B-SCF/B-SDF, which provide interfaces for broadband communication services. For an agent-based mobility management the so called M-SCF/M-SDF are required, providing an execution environment for a VHE agent migrating to corresponding MSCs in case of a location update. Additionally, the SENs (Service Execution Node) should provide an execution platform for agent systems called B-SS&CPs. The corresponding agent execution environment should also be provided by the USIM or by the TE/TA. The logical conjunction of the distributed agent execution environments mentioned above will build up the DAE, which contains the required agents and their service logic residing in different places and communicating through the B-SCF/B-SDF interfaces.

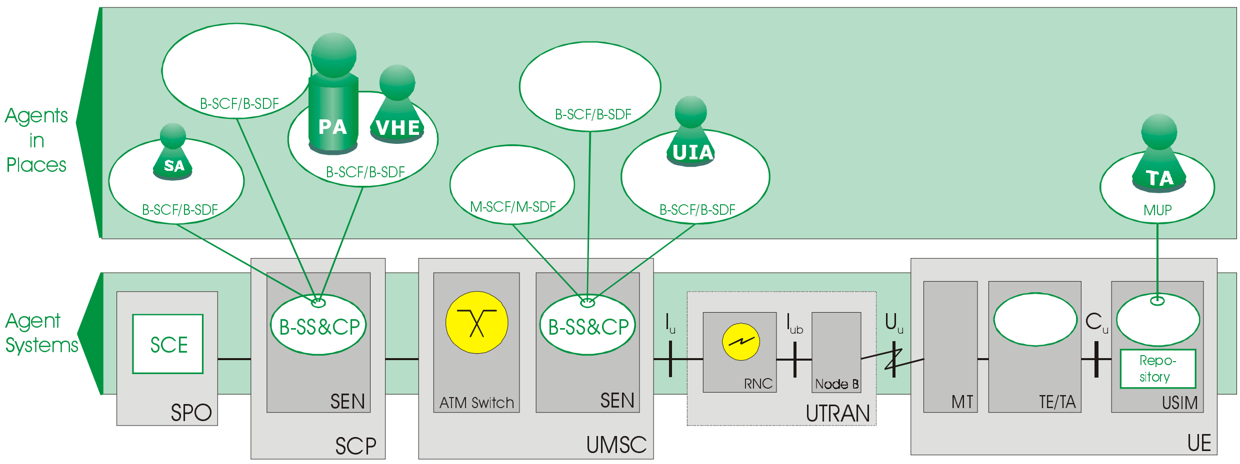

Figure 8 : Distribution of Agents within UMTS

For the following analysis the Voyager platform is evaluated as an agent system. However, as Voyager is based on an ORB architecture, this analysis could be easily adapted to other Java-based agent systems like Grasshopper.

For the fixed part of the network the transfer of the Voyager protocol over ATM should be considered. As Voyager is on top of TCP/IP, Classical IP over ATM with LLC/SNAP (Logical Link Control/Sub-Network Attachment Point) encapsulation is chosen. This implies the availability of the mentioned protocol stack in each UMTS component.

For the transport of the Voyager protocol over the air interface the RLC (Radio Link Control), MAC (Medium Access Control) and LLC protocols should also be taken into the account.

The required agents described before like VHE agent, terminal agent, user interface agent, service agent and provider agent and their assignment to the corresponding places and network components are outlined in figure 8. Additionally, some special agents are included like the SA agent and the PA.

The SA acts as a personal communication manager which handles user's outgoing and incoming communication according to the conditions specified in the user profile which can be configured by each user himself.

Each user is represented by the VHE agent which contains user specific data and can act on behalf of the user. As described in section 2, all services, terminals and VHE agents are registered at the PA .

After the definition of the relevant network components, the agent system and the dedicated agents, now the agent based approach explained above will be mathematically described. The goal is the performance evaluation of the system by comparing the different strategies for service access. These strategies differ in how the agent has to accomplish a certain task. Hereby, the agent migration vs. remote interaction or a combination of both these possibilities have to be taken into account.

4.1 Mathematical Model

For a performance evaluation of the agent based approach described above a mathematical model has to be built allowing a quantitative description of an agent's characteristics like interactivity (i) and mobility (m) (see figure 3) concerning the amount of data and code to be transported over the network as well as the response time considering the underlying protocol stack.

For describing an agent in terms of data size we have defined the parameter (c) which is a measure for classifying different agents depending on the degree of task complexity they have to accomplish.

In case of agent interaction we have just to consider the request and reply data (D_{qi} and D_{pi}) which are in turn a function of the parameter (c).

For an agent's interaction with other agents the agent system provides different possibilities. First the agent can use RMI (Remote Method Invocation) which is similar to a simple RPC (Remote Procedure Call), known from other operating systems. This mechanism is made more feasible by introducing a string based communication channel which uses only a few set of procedures that can be called remotely. These methods use a standardised interface for a dialog oriented communication protocol which applies a defined language called ACL (Agent Communication language). Inside the ACL it is possible to define some inner content languages which are interpreted by the agent. This makes the communication act transparent from the developers point of view.

For our following analysis the employment of pure messaging (RMI), ACL with AVP (Attribute Value Pair) as inner content and ACL with the inner language XML are compared to each other, with regard to their consumption of network resources.

In case of agent migration not only the agent code but also the agent data and the current state of the agent have to be transferred to the destination place. The agent data. Code and state are a function of the parameter (c) as well, which depends on the task the agent has to accomplish.

In some cases the agent has to send back (or to bring) some results to its e.g. home place after migration. In this case another parameter has to be taken into account called selectivity factor (α_m) which defines the ability of filtering the received data before sending (or bringing) the result back to the e.g. home place. Therefore the parameter (c) for reply data is a function of factor α_m.

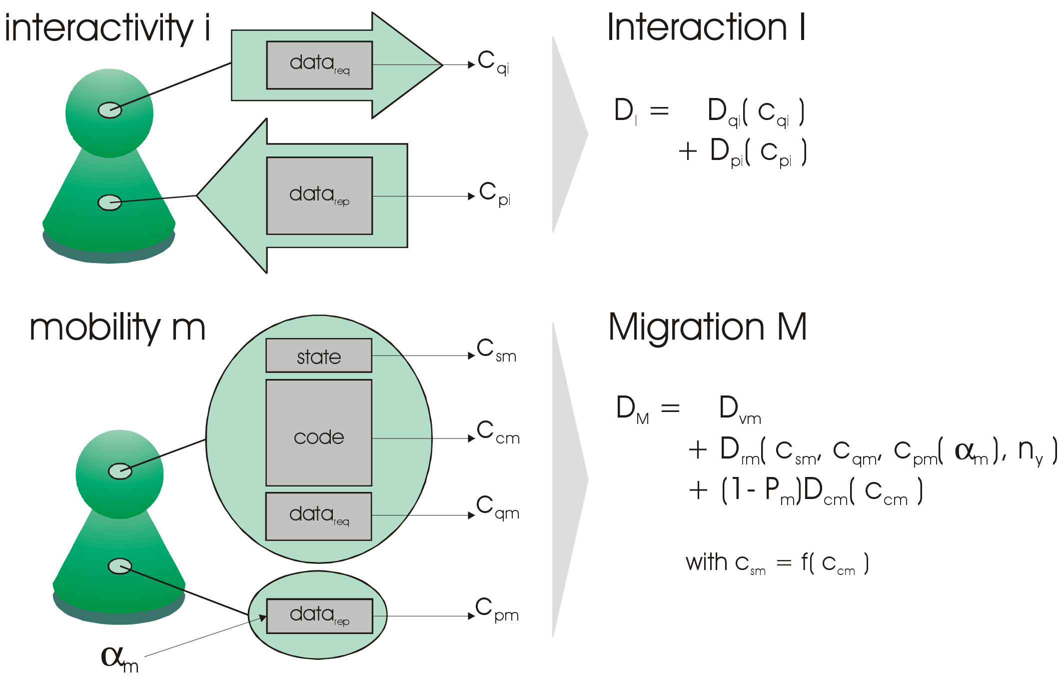

Figure 9: Mathematical Abstraction of an Agent

Now the overall data amount (D_M and D_I) which consider the actually transferred data including all protocol overheads can be calculated for any scenario using the mechanisms described above.

To calculate the response time for a certain task like service request the required time for the transfer of the corresponding data amount for all required agent interactions and migrations is calculated considering the underlying transfer protocol and the assumed bandwidth of the involved links.

In the following this mathematical model is applied for the performance evaluation of the possible strategies for using the VHE and user interface agent (UIA).

4.2 *Usage of the VHE agent*

As mentioned before, there are several possibilities to place and employ the VHE agent. In this section, 4 strategies are investigated for performance evaluation with different possible usage of the VHE agent.

One of the tasks of the service and user management system is indicating the user's subscribed services on his different terminals. There are many possibilities to employ the VHE agent for this task. As the VHE agent represents the user in the network, it should be able to make a pre-selection of available services according to the user's preferences.

Depending on the placement of the VHE agent different response times for the same task will arise.

In every scenario, we assume that fifteen services are available and can be provided by the SE (Serving Environment) which is visited by the mobile user. The VHE agent will select three of those to indicate them on the user's currently used terminal. Additionally three already subscribed services (from the home service provider) will also be indicated on the user's terminal.

4.2.1 Scenario 1

The first possibility is that the VHE agent remains in the HE (home provider domain/Home Environment). This implies that all signalling and data traffic have to be transferred over the whole network (see figure 10).

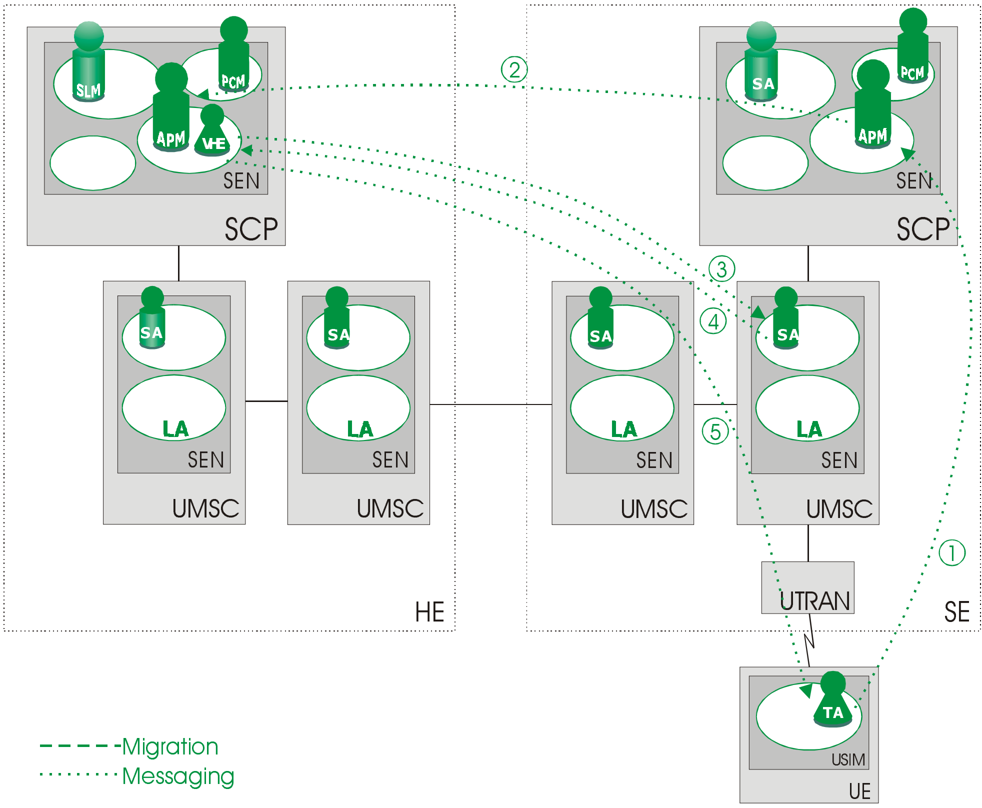

Figure 10: VHE agent Scenario 1: VHE agent remains in HE (central)

The following table lists the calculated response time assuming an average bit rate of 144 Kbit/s over the air interface and 4 Mbit/ s for the fixed part of the network considering the different messaging possibilities explained above.

	Pure Mess. w/ AVP	ACL w/ AVP	ACL w/ XML	Comments
T_{resp} [ms]	1002	1023	1167	@ B_R=144kbit/s, B_W=4Mbit/s
$C_{ServDes}$ [byte]	7605	7755	14385	15 ServDes from SE
$C_{ServDes}$ [byte]	3042	3192	4764	6 ServDes to SE
$C_{VHEdata}$ [byte]	-	-	-	
$C_{VHEcode}$ [byte]	-	-	-	

In the second row the parameter (c) is specified for the transfer of 15 service descriptions from the SE to the HE according to the used messaging mechanism. In the third row the corresponding parameter (c) is specified for the transfer of the selected six service descriptions from the HE to the TA. It can be noticed that using XML as the inner content language produced significantly more data compared to the other messaging mechanisms. However, the response time for using XML is only slightly longer than in other cases. That is because the protocol and network delay are more crucial than the amount of the data that has to be transferred.

4.2.2 Scenario 2

The second possibility is that the VHE agent migrates to the SE and all interactions can be done locally. This strategy will produce the following response time for different messaging mechanisms:

	Pure Mess. w/ AVP	ACL w/ AVP	ACL w/ XML	Comments
T_{resp} [ms]	1081	1115	1267	@ B_R=144kbit/s, B_W=4Mbit/s
$C_{ServDes}$ [byte]	7605	7755	14385	15 ServDes from SE
$C_{ServDes}$ [byte]	3042	3192	4764	6 ServDes to SE
$C_{VHEdata}$ [byte]	2298	2598	4168	CommPer, SecPer, 3 UserEnv, 3 ServDes to SE
$C_{VHEcode}$ [byte]	3860	5018	7334	UPA Code to SE

In addition to scenario 1, here the parameter (c) is considered for both, data and code of the VHE agent migrating to the SE. It can be noticed that the overall response time is longer compared to scenario 1 for each messaging mechanism. It means, that in this special case the additional migration of the VHE agent causes more delay compared to scenario 1.

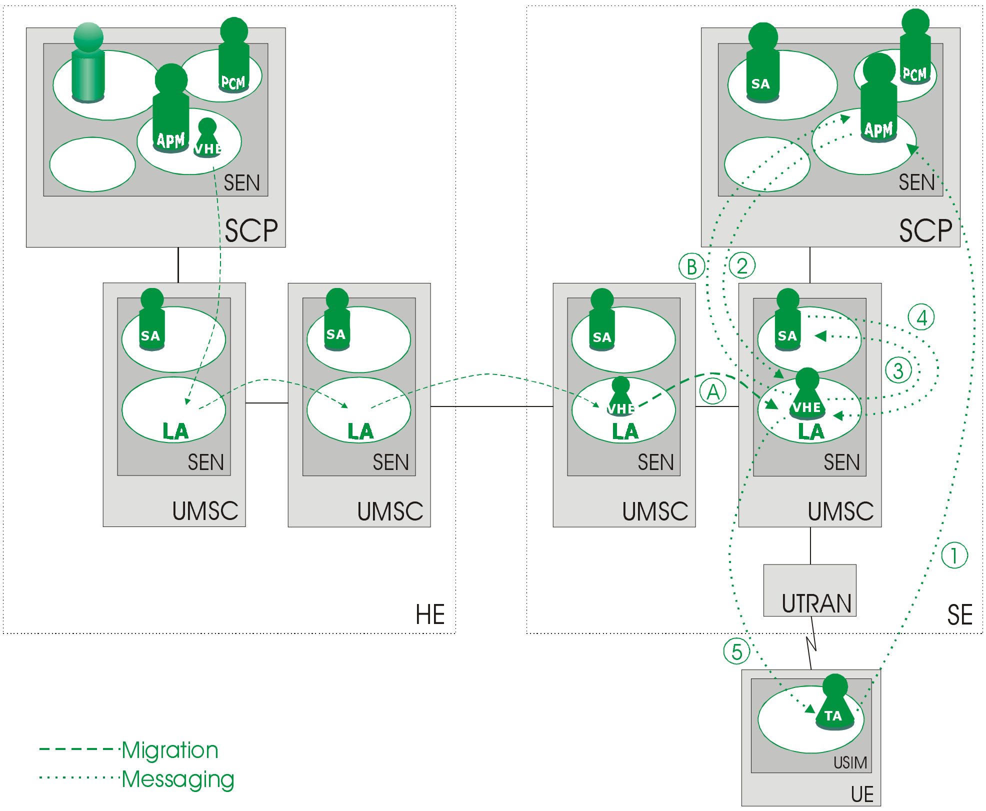

Figure 11: VHE agent Scenario 3: VHE agent follows the User (decentralized)

4.2.3 Scenario 3

The figure 11 illustrates a further strategy for using the VHE agent. In this case the VHE agent follows the user to each new LA (location area) to which the user moves. Assuming the user changes the UMSC while moving, the VHE agent has to change the UMSC as well. For this method all interactions can be accomplished locally leading to a significant improvement of the performance by reducing the data amount transferred over the network which is reflected in the response time specified in the following table:

	Pure Mess. w/ AVP	ACL w/ AVP	ACL w/ XML	Comments
T_{resp} [ms]	864	835	997	@ B_R=144kbit/s, B_W=4Mbit/s
$C_{ServDes}$ [byte]	-	-	-	
$C_{ServDes}$ [byte]	3042	3192	4764	6 ServDes to SE
$C_{VHEdata}$ [byte]	-	-	-	
$C_{VHEcode}$ [byte]	-	-	-	

4.2.4 Scenario 4

The last possibility investigated by our model assumes the availability of the VHE agent in each user's terminal, which migrates to the network after a connection establishment in a new SE. For accomplishing the required interactions the corresponding data and time values are depicted in the following table:

	Pure Mess. w/ AVP	ACL w/ AVP	ACL w/ XML	Comments
T_{resp} [ms]	1805	1923	2218	@ B_R=144kbit/s, B_W=4Mbit/s
$C_{ServDes}$ [byte]	-	-	-	
$C_{ServDes}$ [byte]	1521	1671	2547	3 ServDes to SE
$C_{VHEdata}$ [byte]	777	927	1621	CommPer, SecPer, 3 UserEnv to SE
$C_{VHEcode}$ [byte]	3860	5018	7334	UPA Code to SE

Figure 12 shows the results of the response time for different scenarios described above using messaging with XML content. The response time for different methods are calculated varying available bandwidth over the air interface and core network. It can be noticed that the migrating VHE agent leads to the shortest response time. That is because the VHE agent is already in the user's LA before accessing the service and all interactions can be accomplished locally.

The next shortest response time compared to the other strategies is delivered when the VHE agent remains in the HE, as in this case no migration over the network takes place. The response time for scenario 2 is longer than the one in scenario 3 because of the migration of VHE agent to the SE before beginning with local interactions. The fourth scenario where the VHE agent resides in the user's terminal produces the longest response time which is affected by the limited bandwidth over the air interface when the VHE agent migrates from the terminal to the network.

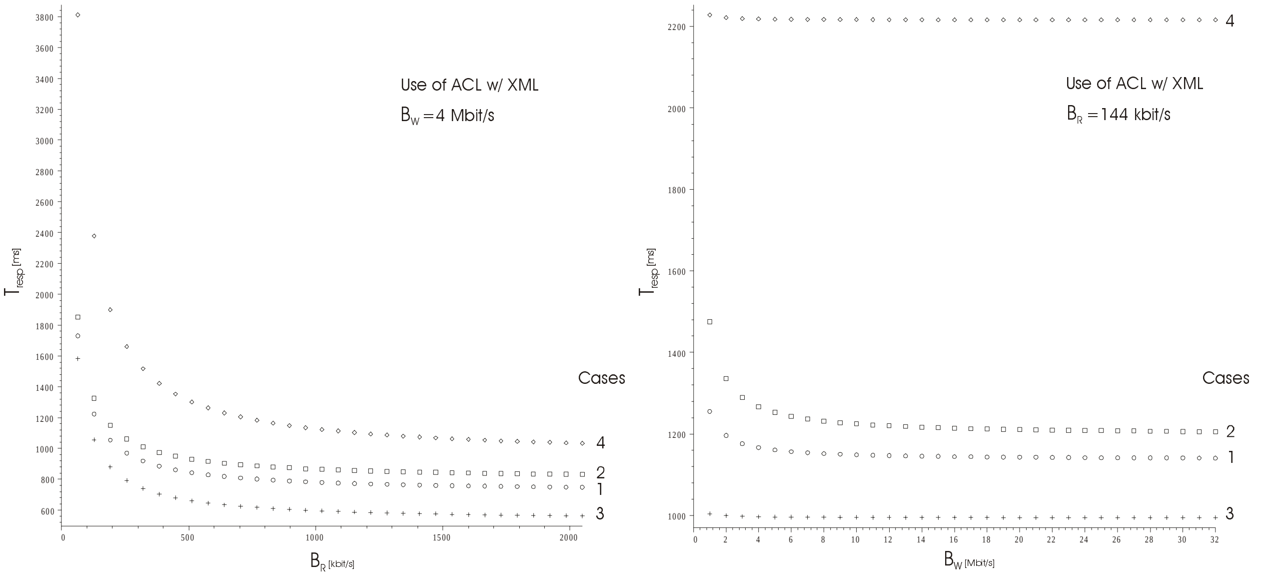

Figure 12: Response Times vs. Bandwidth (scenario 1-4)

4.3 Usage of the UIA

As mentioned before each service has to provide a so called UIA, which acts as an interface between the corresponding service and the user. It contains the service logic for guiding the user through the required steps for using the service on the corresponding terminal. Using the UIA the same service can be presented on terminals with different capabilities.

For evaluating of the UIA a local city information service has been investigated, which can provide the user with a large amount of resulting data as a reaction to a location-based information query.

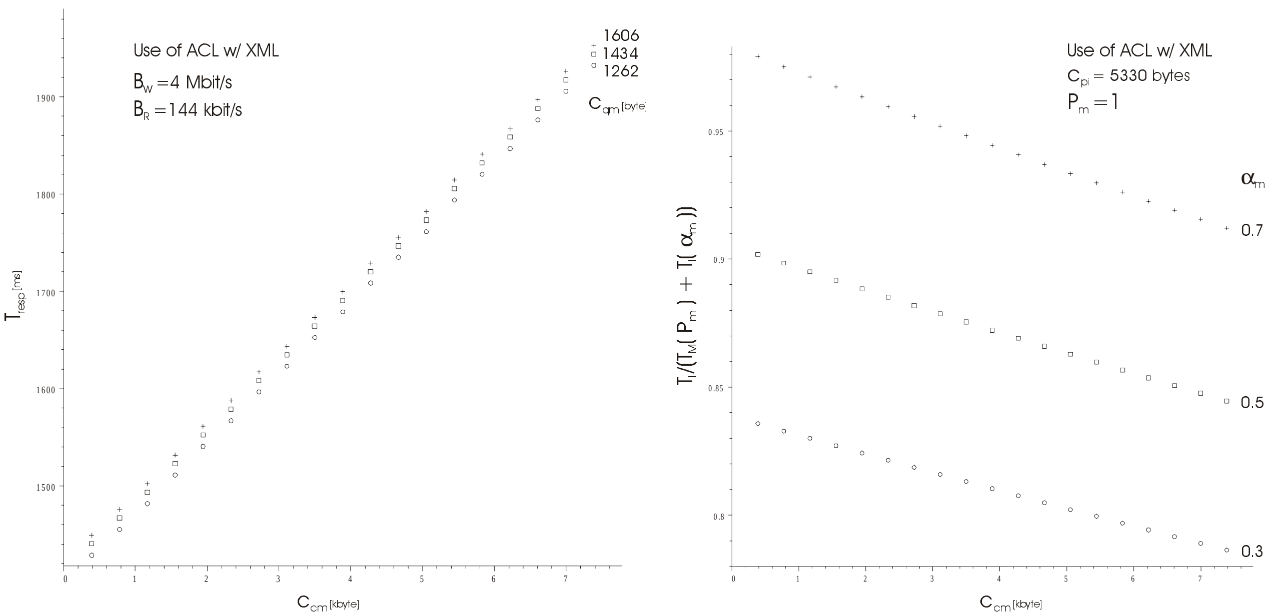

Figure 13: Response Time vs. Task Complexity

The left graph in Figure 13 shows the calculated response times for service access depending on different task complexities of the UIA for varying size of the query (C_{qm}), while the right one presents the ratio T_l / ($T_M(P_m)$+ $T_l(\alpha_m)$) (it is a measure to compare the response time using messaging and the overall response time using agent migration) vs. different task complexities of the UIA for varying selectivity factor of the agent (α_m).

T_I : Interaction time

$T_M(P_m)$: Migration time depending on the probability of the previous agent code existence in the corresponding place

$T_I(\alpha_m)$: Interaction time depending on agent selectivity (Filtering of the data have to be replied)

It can be noticed that this ratio varies between 0.8 and 1 for one interaction. For a number (n) of interactions this ratio must be multiplied by (n). If the ratio has a value bigger than 1, it implies that a previous migration of the UIA would provide a better performance than the method using only remote interactions.

One of the significant advantages using mobile agents for service provisioning is the possibility to bring the service logic from the HE to the SE for local execution, which leads in many cases to a considerable performance improvement. The right graph in figure 14 shows the total data amount transferred over the network due to agent migration from HE to SE depending on different agent code complexities.

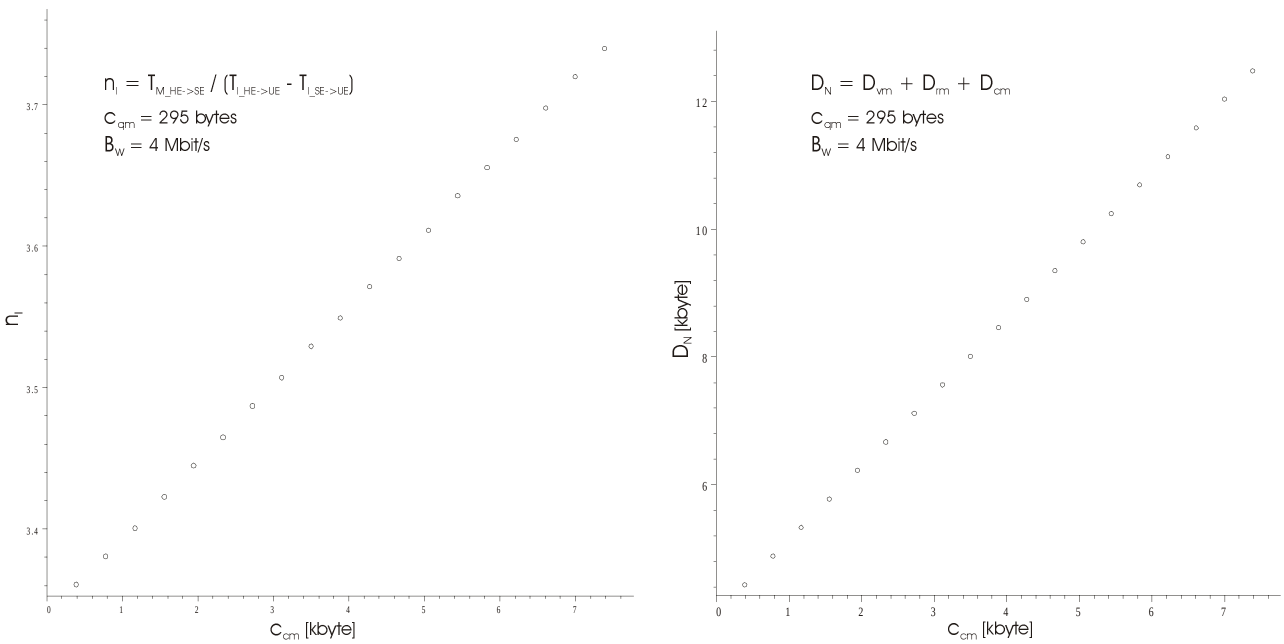

Figure 14: Number of Interactions vs. Task Complexity

The left graph in figure 14 compares the possibility of remote interactions between HE and UE to the possibility of previous service logic migration from HE to SE and local interactions between SE and UE. This comparison is described by the ratio $n_I = T_{M\_HE>SE} / (T_{I\_ HE>UE} - T_{I\_ SE>UE})$ depending on the different agent code complexities. Thereby, n_I is the lower limit of the number of interactions that justifies a previous agent migration.

$T_{M\_HE>SE}$: Migration time from HE to SE

$T_{I\_ HE>UE}$: Interaction time between HE and UE

$T_{I\_ SE>UE}$: Interaction time between SE and UE

It can be noticed that n_I ranges from 3.12 to 3.76. This implies that in practical use cases a previous agent migration would lead to a performance improvement for n_I larger than 4.

Further work in this area will include evaluations for a wide range of parameters so that more general conclusions can be drawn.

5 Conclusion

This paper has described an advanced mobile agent-based approach for a realisation of the VHE (Virtual Home Environment) concept. The results and experiences in the CAMELEON project have shown the potential benefits of mobile agent technology for future telecommunication networks, e.g. UMTS which can be integrated with other technologies (e.g. CAMEL/IN) in order to allow flexible service provisioning, execution and access. Several aspects need further investigations – especially from a network operator point of view. The unsolved security risks need to be reduced to an acceptable minimum. Furthermore, the combination of the presented strategies has to be evaluated in the context of realistic mobility models.

6 Acronyms

ACL	Agent Communication Language
AN	Access Network
APM	Adaptive Profile Manager
ATM	Asynchronous Transfer Mode
AVP	Attribute Value Pair
B-ISDN	Broadband ISDN
BSS	Base Station Subsystem
CAMEL	Customised Applications for Mobile network Enhanced Logic
CAMELEON	Communication Agents for Mobility Enhancements in a Logical Environment of Open Networks
CN	Core Network
DAE	Distributed Agent Environment
DPE	Distributed Processing Environment
ETSI	European Telecommunications Standardisation Institute
FIPA	Foundation for Intelligent Physical Agents
FPLMTS	Future Public Land Mobile Telecommunication System
GEMPLUS	http://www.gemplus.com
GRAN	Generic Radio Access Network
GSM	Global System for Mobile Communications
HE	Home provider domain/Home Environment
HLR	Home Location Register
IMT-2000	International Mobile Telecommunication for the year 2000
IP	Intelligent Peripheral
iPCSS	Intelligent Personal Communication Support System
ISDN	Integrated Services Digital Network
IWU	InterWorking Unit
LA	Location Area
LLC	Logical Link Control
MA	Mobile Agent
MAC	Medium Access Control
MASIF	Mobile Agent System Interoperability Facility
MARINE	Mobile Agent Environments In Intelligent Networks
MCS	Mobile Communication System
MS	Mobile Station
MSC	Mobile Switching Center
MT	Mobile Termination
OMG	Object Management Group
PA	Provider Agent
PCS	Personal Communications Support
PCSS	Personal Communication Support System
QoS	Quality of Service
RAN	Radio Access Network
RLC	Radio Link Control
RMI	Remote Method Invocation
RPC	Remote Procedure Call
SA	Service Agent
SC&MMP	Service Control and Mobility Management Platform
SCF	Service Control Function
SCP	Service Control Point
SDF	Service Data Function

SE	Serving Environment
SEN	Service Execution Node
SMS	Short Message Service
SNAP	Sub-Network Attachment Point
SP	Service Provider
SSP	Service Switching Point
TA	Terminal Agent
TE	Terminal Equipment
TINA	Telecommunication Information Networking Architecture
UIA	User Interface Agent
UMTS	Universal Mobile Telecommunications System
UPT	Universal Mobile Telecommunication
USIM	Universal Service Identification Module
VHE	Virtual Home Environment
VLR	Visitor Location Register

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