

# Terminal Management and Intelligent Access Selection in Heterogeneous Environments

Artemis A. Koutsorodi · Evgenia F. Adamopoulou ·  
Konstantinos P. Demestichas · Michael E. Theologou

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**Abstract** This paper presents a mobile terminal architecture for devices operating in heterogeneous environments, which incorporates intelligence for supporting mobility and roaming across legacy access networks. It focuses on the structure and functionality of the proposed scheme that supports terminal-initiated and terminal-controlled access network selection in heterogeneous networks. It discusses the decomposition of the proposed Terminal Management System into separate modules, responsible for retrieving link-layer measurements from the attachment points in the terminal's neighborhood, for handling the user's profile and for performing intelligent access network selection. This latter function aims at independently determining the optimal local interface and attachment point through which applications can be obtained as efficiently as possible, by taking into account network status and resource availability, user preferences and service requirements.

**Keywords** access selection · always best connected · optimization process · user preferences

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A. A. Koutsorodi (✉) · E. F. Adamopoulou ·  
K. P. Demestichas · M. E. Theologou  
School of Electrical and Computer Engineering,  
National Technical University of Athens,  
9 Iroon Polytechniou St., Zographou,  
157 73 Athens, Greece  
e-mail: artemis@telecom.ntua.gr

E. F. Adamopoulou  
e-mail: e100008@mail.ntua.gr

K. P. Demestichas  
e-mail: e100014@mail.ntua.gr

M. E. Theologou  
e-mail: theolog@cs.ntua.gr

## 1 Introduction

The next generation of mobile systems is expected to comprise heterogeneous networks consisting of diverse radio segments, able to host multimode wireless terminals, each of them capable of alternatively operating in the diverse radio segments available in the infrastructure. The different radio segments, or access technologies (e.g., WLANs, cellular and broadcast networks) will thus constitute cooperating components of a composite radio infrastructure and will be interconnected by a backbone (e.g., an IP-based fixed network) and jointly operated in an optimized fashion that will allow for an improved overall resource management [1].

A challenging issue related to the above is the development of management frameworks, both for the terminal and the network [2, 3], that will enable ubiquitous service provisioning regardless of the network the end user is connected to, thus allowing the latter to benefit from being able to access his/her subscribed services anywhere and anytime. Another important aspect is the fact that the user will need to control the usage of the available networks, especially when this usage comes with a price [4]. This involves a potentially complex decision making process which may be guided by policy management tools, with support from both the user terminals and the networks, thus giving rise to the significant issue of optimally distributing intelligence between the network and the mobile terminal in order to support seamless mobility and service provisioning.

Consequently, the exploitation of the composite radio infrastructure requires innovative management schemes. The deployment of a central network and

service management system represents one solution. An alternative, decentralized approach is to capitalize on the growing capabilities and computational power of today's mobile terminals to remove some of the management work-load from network equipment and to distribute it to the terminals [5].

In this paper, we argue that appropriate functionality must be in place at the mobile terminal to handle basic mobility management tasks and to support the applications in dealing with the dynamics and heterogeneity of available access networks. We discuss a management architecture for composite radio infrastructures that incorporates an innovative Terminal Management System (TMS), located at the mobile terminal and capable of dynamically and independently selecting the appropriate access network through which services can be obtained efficiently in terms of cost and QoS, in a transparent manner. The work of this paper is generic with respect to the wireless technologies included in the composite radio infrastructure. These technologies can comprise cellular networks (2.5G or 3G) [6, 7], Broadband Fixed Wireless Access (BFWA) systems and WLANs [8, 9], or terrestrial Digital Video Broadcasting (DVB-T) systems [10]. In any case, the exploitation of this infrastructure calls for the development of an appropriate, sophisticated TMS that should be capable of:

- Detecting available access networks and their capabilities.
- Selecting, activating and configuring the connections to appropriate attachment points.
- Accessing, modifying and storing the user profile.
- Supporting the applications in handing over the existing connections from one access network to another in a seamless manner.

The TMS must be modelled for a modern, general-purpose operating system, running on a mobile terminal that may be continuously switched on [11, 12]. Power management and power conservation issues are out of scope.

There are several arguments for the terminal to incorporate functionality for performing access network selection: First of all, the terminal is the entity that is aware of the different access technologies in its surroundings for two reasons: (a) it knows which hardware interfaces it has implemented, and (b) it can detect the availability of access networks in its physical surroundings [13]. Moreover, as the decision to initiate a handover, as well as the handover target selection process itself, may be based on user preferences, the terminal may provide the user with his options on a GUI, and the user may also be able to

switch interfaces on or off manually and even dynamically alter his preferences.

Optimal system operation is to be achieved through the joint contributions of both the network and the terminals: On the network's side, the network management entity will perform tasks such as the balancing of the traffic load between the different access networks, and the general coordination thereof—the goal being optimal joint resource management. On the terminal's side, the TMS will be responsible for detecting available access networks in the mobile terminal's neighbourhood, for making the optimal selection, based on network availability, services and user preferences, of the appropriate interface(s) through which services may be provided to the user, and for interacting with the network management system, both for submitting its decisions for approval and for receiving network-initiated handover decisions. This interaction will ensure that the network's and the terminal's estimations of radio conditions and QoS levels in the infrastructure are beneficially combined for making an educated selection of the appropriate access technologies through which services can be obtained as efficiently as possible. Thus, both the network and the terminals contribute intelligence towards optimal system operation.

The paper is structured as follows: Section 2 introduces a TMS architecture and describes the functionality of each of its modules. Section 3 provides the formal description and the solution of the intelligent access selection problem. Finally, Sections 4 and 5 include simulation results and concluding remarks, respectively.

## 2 Terminal management architecture

### 2.1 Overview

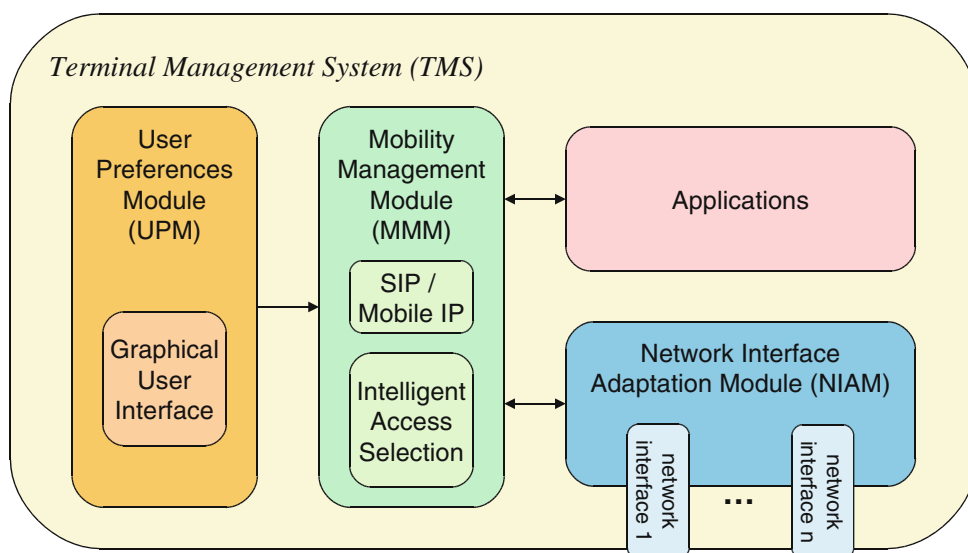
Figure 1 illustrates the main components of the TMS architecture, namely the Network Interface Adaptation Module (NIAM), the Mobility Management Module (MMM) and the User Preferences Module (UPM).

The NIAM is responsible for providing the terminal with a level of abstraction from the different network drivers, the UPM for accessing and processing the user profile, and the MMM for handling mobility events and for optimally computing handover targets. The following paragraphs discuss these modules in more detail.

### 2.2 Network Interface Adaptation Module (NIAM)

The NIAM is responsible for identifying the different interfaces present in the terminal, for monitoring their

**Figure 1** TMS architecture



status, for collecting measurements from each interface and for executing the selection and de-selection of the appropriate interface. More specifically, the NIAM serves two purposes: (a) the connection and de-connection of the appropriate interface during power-up of the mobile terminal or during a handover and (b) the retrieval of layer-2 measurements in the network interface. This means that the NIAM is able to provide the terminal with measurements retrieved from the different network drivers, reflecting the signal quality or connectivity status in each of these interfaces in an abstracted way (e.g., good, average or poor signal strength). In all, the NIAM is able to provide the terminal with a list for each attachment point in the terminal’s neighbourhood, each list comprising information about the attachment point’s signal strength and bandwidth availability, its type of technology, its network operator and about the cost at which it is able to provide each available service at each of the service’s permissible quality levels. This set of parameters, coupled with some additional pieces of information as will be explained in the following, constitutes a minimal set based on which the terminal can perform intelligent access selection in a multiple access environment.

Therefore, the NIAM should incorporate a mechanism for retrieving such measurements from attachment points in its range (such as the Candidate Access Router Discovery protocol [14]) and for processing this information in order to detect if a new attachment point has appeared in the terminal’s neighbourhood, if an old one has disappeared, or if the perceived signal strength from an already selected attachment point has severely deteriorated. In all of

these cases, the MMM is notified accordingly for the purpose of triggering the process of optimally distributing all running applications to appropriate interfaces and quality levels.

### 2.3 User Preferences Module (UPM)

The UPM is responsible for storing, accessing and editing the user’s profile. A graphical user interface (GUI) through which the user will be able to specify his preferences, will allow the user to give different priorities to parameters that may influence the access network selection process. This prioritization is equivalent to the specification of values for the different coefficients  $w_q$ ,  $w_o$ ,  $w_t$  and  $w_c$ , which correspond to parameters ‘quality’ (i.e., the maximum QoS that the user is willing to be charged for), preferred ‘network operator,’ preferred ‘technology type’ and ‘cost’ (i.e., the maximum cost the user is willing to pay), respectively, and represent the measure by which each one of these parameters is weighted in the access network selection algorithm. For example, if the user chooses to specify that at a given moment ‘quality’ is for him the most important factor in access network selection, ‘technology type’ comes second, ‘cost’ comes third and last comes ‘network operator,’ then the respective coefficients will be assigned values  $w_q > w_t > w_c > w_o$ .

### 2.4 Mobility Management Module (MMM)

The MMM is responsible for handling all events relating to mobility management and access network selection. It incorporates Session Initiation Protocol

(SIP) and Mobile IP functionality as well as an appropriate decision algorithm for selecting the optimum available attachment point.

More specifically, SIP is used as an application layer protocol whose main functionalities are application level set-up and application level session management [15], while an IP mobility protocol such as Mobile IP [16, 17] provides an IP-layer solution for making movements on the IP layer transparent to higher protocol layers. Additionally, work is currently underway [18, 19] to extend mobility protocols in order to allow seamless IP handover. A pre-requisite for the seamless IP mobility protocols is the mobile node's ability to choose an appropriate handover target based on a match between the mobile node's (and the user's) requirements and the handover candidate's capabilities. This functionality is carried out by the Intelligent Access Selection (IAS) function, which is incorporated in the MMM.

The IAS function is responsible for optimally selecting the mobile terminal's local interface (technology) and the network's point of attachment (access router, access point), both in the case of an intra-technology handover (horizontal HO) and in the case of an inter-technology handover (vertical HO), based on service requirements, user preferences and current network availability.

The MMM is responsible for providing the IAS function with the required input (retrieved from the UPM and the NIAM), for triggering its execution and,

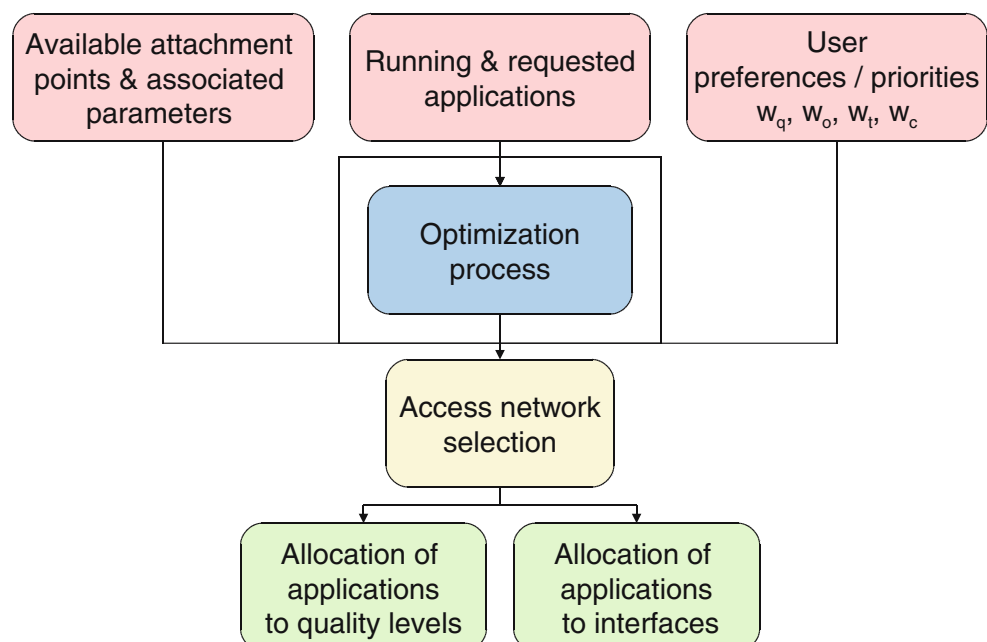
finally, for relaying its decisions to the NIAM for handover execution.

### 3 Intelligent Access Selection (IAS)

The IAS function is triggered in the following cases: (a) when a new service request appears; (b) when the user changes his/her profile, and therefore the weights  $w_q$ ,  $w_o$ ,  $w_t$ ,  $w_c$  attributed to the different selection criteria are altered; (c) when the NIAM issues a notification of severe signal degradation or complete signal loss; (d) when the availability of a new attachment point or the unavailability of an old one is detected by the NIAM. Whenever one of the aforementioned events occurs, the IAS algorithm is executed for the purpose of finding the optimal attachment point both for the provision of the newly requested service (in the case of trigger (a)), and for the possible handover of the already running services to newly computed optimal attachment targets. The optimization process carried out by the IAS is illustrated in Fig. 2.

The optimization problem relies on the following input data: (a) a set of measurements reflecting the availability, signal quality and other parameters perceived from each of the available attachment points, as provided by the NIAM; (b) the set of applications that are already running on the mobile terminal, the corresponding quality levels at which these applications are being provided as well as the set of applications that

**Figure 2** Intelligent access selection optimization process



the user is requesting to use; (c) the set of user preferences, according to which the parameters ‘quality,’ ‘network operator,’ ‘technology type’ and ‘cost’ are prioritized.

The optimally computed access network selection is equivalent to an optimal allocation of both the requested and the already running services to appropriate quality levels, and an optimal allocation of the requested services to network interfaces. These allocations are bound to certain constraints: (a) every application should be allocated to an acceptable quality level; (b) the quality level requested by the user should be guaranteed; (c) the user’s preferences should be satisfied in the specified order.

The aforementioned allocations should optimize an objective function associated with the weights attributed to the different selection criteria, and computed for each of the requested/running applications separately. Let  $P$  be the set of attachment points that the terminal perceives,  $P = \{p_1, p_2, \dots, p_n\}, n \in \mathbb{Z}$ , and  $Q(p)$  the set of quality levels at which attachment point  $p$  can offer the service under consideration,  $Q(p) = \{q_1, q_2, \dots, q_m\}, m \in \mathbb{Z}$ . The goal is the computation of:

$$OF(p, q) = w_q \times \text{Quality}(p, q) + w_o \times \text{Operator}(p) + w_t \times \text{Technology}(p) - w_c \times \text{Cost}(p, q) \tag{1}$$

for all  $p \in P$  and  $q \in Q(p)$ , and the determination of:  $\max_{p \in P} \{ \max_{q \in Q(p)} \{ OF(p, q) \} \}$  as the optimal attachment point and quality level for each of the requested/running services.

In the proposed implementation, coefficients  $w_q, w_o, w_t$  and  $w_c$  are assigned values 0.8, 0.6, 0.4 or 0.2, according to the position of factors ‘quality,’ ‘cost,’ ‘technology type’ and ‘network operator’ in a prioritized list. That is the coefficient that corresponds to the first and most important factor will be assigned the value 0.8, the coefficients corresponding to the second, third and fourth factors will be assigned the values 0.6, 0.4 and 0.2, respectively.

Factor  $\text{Quality}(p, q)$  in Eq. 1 is not an expression of the nominal quality level offered by each attachment point, but rather an expression of the combined effect of the nominal quality level and the perceived signal strength from each attachment point. Therefore:

$$\text{Quality}(p, q) = q_s(p) \times q$$

where  $q_s(p)$  expresses the strength of the received signal from access point  $p$ , and  $q$  expresses the quality

level at which attachment point  $p$  can offer the service under consideration. If five different levels for signal strength are assumed, coefficient  $q_s(p)$  may be assigned the following values:

$$q_s(p) = \begin{cases} 1.0, & \text{for signal level 5 (excellent signal)} \\ 0.95, & \text{for signal level 4} \\ 0.8, & \text{for signal level 3} \\ 0.6, & \text{for signal level 2} \\ 0.4, & \text{for signal level 1 (weak signal)} \end{cases}$$

Factor  $\text{Cost}(p, q)$  in Eq. 1 represents the cost of a specific allocation decision, i.e., the cost at which attachment point  $p$  can offer the service under consideration at quality level  $q$ . In the proposed implementation, information about the cost at which services are offered is received from the network every time the mobile terminal powers up, or at regular time intervals (e.g. once a day), and is stored in the terminal in the form of an XML document. This document does not need to be updated very frequently (e.g., more than once a day), as changes in the operators’ offered prices are not likely to occur that often. The data in this document correspond to the cost of a service being provided at a specific quality level, by a specific network operator and through a specific technology, per data volume unit (e.g., kilobyte) or per time unit (e.g., second).

The basic guidelines that were followed in order to construct an appropriate XML document containing cost-related information are the following:

- Higher quality levels are offered at higher costs.
- WLAN technology offers most services at a lower cost.
- UMTS technology is slightly more expensive, for most services, compared to GSM.
- For most services, DVB technology is more expensive, compared to other access technologies, with the exception of video-related services, e.g., video streaming, video call, etc.

The cost values that are retrieved from the XML document are normalized by the optimization algorithm before being used in the computation of the objective function. The normalization process is necessary in order to convert the values of factor  $\text{Cost}(p, q)$  to a scale that renders them comparable to the values of  $\text{Quality}(p, q)$ .

Let  $\text{actualCost}(p, q)$  be the cost per unit of the requested service, as it is retrieved from the XML document,  $\text{maxCost}$  the maximum cost per unit for this specific service and  $\text{noQosLevels}$  the number of the

different QoS levels that the service can be provided at. Then:

$$\text{Cost}(p, q) = \frac{\text{noQoSLevels}}{\text{maxCost}} \times \text{actualCost}(p, q).$$

Finally, as far as the factors  $\text{Operator}(p)$  and  $\text{Technology}(p)$  in Eq. 1 are concerned, the user has the capability to specify a preferred network operator and a preferred technology type, through a graphical user interface. In case a candidate attachment point belongs to the preferred operator and/or supports the preferred technology, it is granted a ‘bonus.’ The value of this bonus is a percentage of the absolute value of the following difference:

$$w_q \times \text{Quality}(p, q) - w_c \times \text{Cost}(p, q)$$

and in the proposed implementation stands as follows:

$$\text{Provider}(p) = \begin{cases} 0.5 \times \text{Abs}[w_q \times \text{Quality}(p, q) \\ -w_c \times \text{Cost}(p, q)], & \text{if they match} \\ 0, & \text{otherwise} \end{cases}$$

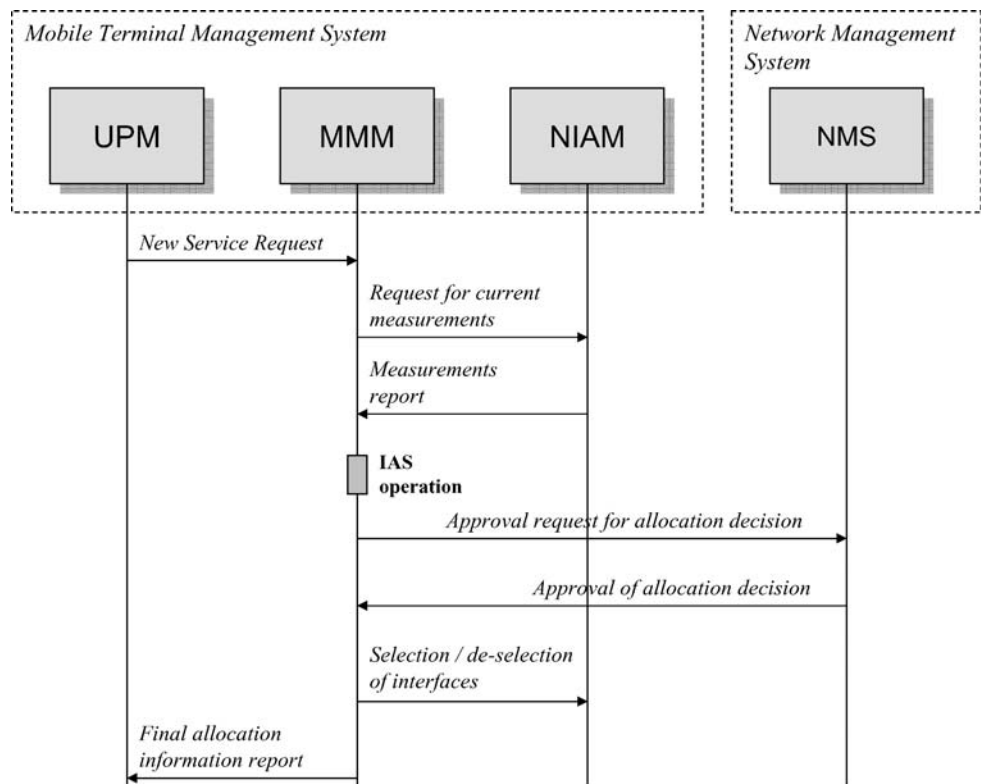
$$\text{Technology}(p) = \begin{cases} 0.25 \times \text{Abs}[w_q \times \text{Quality}(p, q) \\ -w_c \times \text{Cost}(p, q)], & \text{if they match} \\ 0, & \text{otherwise} \end{cases}$$

Figure 3 illustrates a sample scenario of TMS operation, in the case where the IAS algorithm is triggered by a new service request.

As illustrated in Fig. 3, the user requests the provision of a particular service through the GUI. The MMM is responsible for retrieving current measurements that reflect the network status, by submitting an appropriate request to the NIAM, and subsequently for initiating the IAS algorithm. As soon as the best allocation decision has been made, the MMM submits an approval request to the network management entity (NMS) concerning its decision. In case of rejection, the MMM suggests the next best solution that has been computed, and so on. Once an approval response has been received, the MMM instructs the NIAM to select the appropriate interface through which the requested service will be delivered. Furthermore, it supplies the GUI with the information that should be presented about the newly established connection.

In case of an IAS trigger being initiated by a change in the user profile, the sequence diagram is exactly the same. As far as the other cases of IAS triggers are concerned (severe signal degradation, availability of a new attachment point or unavailability of an old one) the information exchange between the different modules of the TMS is quite similar, differing only in that

**Figure 3** Sample scenario of TMS operation



**Table 1** Available and maximum quality levels for services in scenario

	Voice call	SMS	MMS	E-mail	Video call	Video streaming	Web browsing
Total number of quality levels	5	1	2	1	5	5	5
Maximum allowed quality level	3	1	2	1	3	4	4

the initial notification of the MMM is made by the NIAM.

**4 Simulation**

The IAS algorithm’s functionality is tested within the framework of a scenario that simulates a typical day in the life of a businessman, Mr. Green.

**4.1 Scenario description**

Mr. Green commutes from his home to his office, using both his car and the subway to get there. He exploits the time needed to reach his office by making use of several services via his 4G terminal, supplied at the most appropriate quality levels and through connections to the best available access networks (GSM, UMTS, WLAN or DVB) (Table 1).

The user profile in use during this time specifies that ‘cost’ is the most important factor in access network selection, ‘quality’ comes second, ‘network operator’ comes third and ‘technology type’ comes fourth. This

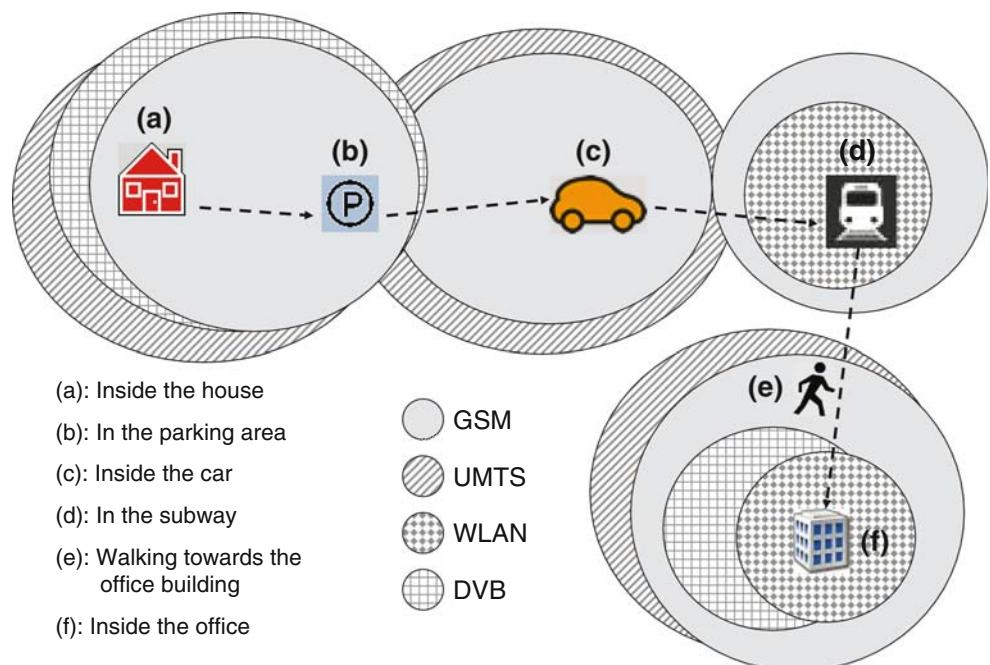
implies the following values for coefficients  $w_i$ :  $w_c=0.8$ ,  $w_q=0.6$ ,  $w_o=0.4$  and  $w_t=0.2$ . Mr. Green has not specified any preferred choice, neither for ‘network operator’ nor for ‘technology type.’

Figure 4 illustrates Mr Green’s route, from his home to his office, along with the area coverage in each step of this scenario. In the following, a detailed, stepwise description of the scenario and of the corresponding allocations of services to networks and quality levels is given. For every allocation that is computed, the algorithm’s execution time is given within parentheses (in milliseconds). As may be observed, in all cases this time is less than 0.3 s, and could be reduced to even less if the execution time of the result recording process in a log file were not taken into account.

**4.2 Results**

Table 2 presents a list of all available attachment points, during the course of the scenario. For each attachment point, the signal level in each step of the scenario is given in a scale from 1 (weakest) to 5 (strongest).

**Figure 4** Network coverage in scenario



**Table 2** Signal levels from available attachment points in scenario steps.

Access point	Operator number	Inside the house	In the parking area	Inside the car	In the subway	Walking towards the office	Inside the office
GSM #1	1	5	2	n/a	n/a	n/a	n/a
GSM #2	1	n/a	3	5	n/a	n/a	n/a
GSM #3	2	n/a	n/a	n/a	5	n/a	n/a
GSM #4	2	n/a	n/a	n/a	n/a	4	4
UMTS #1	1	5	2	n/a	n/a	n/a	n/a
UMTS #2	3	n/a	3	5	n/a	n/a	n/a
UMTS #3	2	n/a	n/a	n/a	n/a	5	5
WLAN #1	5	n/a	n/a	n/a	4	n/a	n/a
WLAN #2	6	n/a	n/a	n/a	n/a	n/a	5
DVB #1	4	5	1	n/a	n/a	n/a	n/a
DVB #2	4	n/a	n/a	n/a	n/a	n/a	5

#### 4.2.1 Inside the house

Mr. Green gets up in the morning and powers up his 4G terminal. He initiates a video streaming service, for a live update of the latest news from the stock market. He also sends an SMS to his partner to confirm the time of today's meeting. A while later, he decides that he would like to watch the stock market news at a better quality level, so he changes his active profile, specifying 'quality' as the most important factor and 'cost' as the second factor ( $w_q=0.8$ ,  $w_c=0.6$ ,  $w_o=0.4$ ,  $w_t=0.2$ ).

IAS is triggered by new service requests (video streaming, SMS), as well as a change in the user profile.

Before the change in the user profile, IAS selects:

- DVB #1, video streaming, QoS-1 (293 ms)
- GSM #1, SMS, QoS-1 (78 ms)

As an example, the grade of the first allocation is computed, using formula (1), as follows: Let  $p_1$ =DVB #1, and  $q_1=1$  (quality level 1). Then:

$$\begin{aligned} OF(p_1, q_1) &= 0.6 \times \text{Quality}(p_1, q_1) + 0.4 \times \text{Operator}(p_1) \\ &\quad + 0.2 \times \text{Technology}(p_1) - 0.8 \\ &\quad \times \text{Cost}(p_1, q_1) \end{aligned}$$

where  $\text{Quality}(p_1, q_1) = q_s(p_1) \times q_1 = 1.0 \times 1 = 1$ ,  $\text{Operator}(p_1) = 0$ ,  $\text{Technology}(p_1) = 0$ , and  $\text{Cost}(p_1, q_1) = \frac{\text{noQoSLevels}}{\text{maxCost}} \times \text{actualCost}(p_1, q_1) = \frac{5}{0.95} \times 0.0085 \cong 0.0447$ , hence:

$OF(p_1, q_1) = 0.56421$ . Grades for  $p_2$ =UMTS #1 and  $p_3$ =GSM #1 are computed in a similar way. The IAS finally results in allocating video streaming to  $p_1$ =DVB #1 and  $q_1=1$  as  $OF(p_1, q_1) > OF(p_i, q_j)$ ,  $\forall i, j$ , where

$i \times j \neq 1$ ,  $i \leq 3$  and  $j \leq 4$  (quality level 4 is the maximum level allowed for the video streaming service).

Reason for this allocation: For video-related services (e.g., video streaming), the DVB network offers lower prices, so it is preferred compared to a GSM or UMTS network. Quality level 1 is selected, as this is the cheapest one (the user has specified 'cost' as the most important factor). As far as the Short Message Service is concerned, it is provided through the GSM attachment point, as this is the most cost-effective solution.

After the change in the user profile, IAS selects:

- DVB #1, video streaming, QoS-4 (293 ms)

Reason for this allocation: The DVB network is selected because it offers high bit rates at low cost, for video-related services (e.g., video streaming). Quality level 4 is the maximum allowed and it is preferred as the user has now specified 'quality' as the most important factor.

#### 4.2.2 In the parking area

Mr. Green leaves his house and heads towards the parking area. He continues to use the video streaming service as he walks. As he gets closer to the parking area, new attachment points become available, while the signal received from the attachment points available in step (a) is getting weaker.

IAS is triggered by the availability of new attachment points (GSM #2, UMTS #2). IAS selects:

- UMTS #2, video streaming, QoS-3 (125 ms)

Reason for this allocation: The appearance of new available attachment points leads to the reconsideration of the current allocation of the video streaming service. UMTS #2 now becomes the best option for the



running service, as it provides significantly better signal strength than attachment points DVB #1, GSM #1 and UMTS #1. Quality level 3 is selected, as quality level 4 cannot be delivered through a UMTS attachment point, due to bandwidth limitations. Compared to UMTS #2, attachment point GSM #2 has the disadvantage of not being able to offer the video streaming service at quality level 3 or higher, due to limited bandwidth capabilities.

4.2.3 Inside the car

Mr. Green gets in his car and terminates the video streaming service. He drives towards the nearest subway station. As he encounters a traffic jam, he decides to take advantage of the time needed to get to the station, so he makes a change to his profile, specifying Operator #3 as his preferred one, and then he initiates a web browsing service, in order to download a large file containing a report about the company’s financial status.

IAS is triggered by a new service request (web browsing). IAS selects:

- UMTS #2, web browsing, QoS-4 (47 ms)

Reason for this allocation: Attachment point UMTS #2 is selected, because it belongs to the preferred operator (Operator #3), and as a result it is granted a ‘bonus’ by the IAS algorithm. Quality level 4 is the maximum allowed and it is preferred as the user has specified ‘quality’ as the most important factor.

4.2.4 In the subway

Mr. Green arrives at the subway station. The download of the financial report from the web is still ongoing. As his train is delayed, Mr. Green realizes he will not be able to make it to the office on time for his morning meeting. Therefore, he initiates a video call, in order to participate in the meeting from the subway.

IAS is triggered by the unavailability of access point UMTS #2, through which web browsing is being

delivered, and also by a new service request (video call). IAS selects:

- WLAN #1, web browsing, QoS-4 (47 ms)
- WLAN #1, video call, QoS-3 (46 ms)

Reason for this allocation: WLAN technology is preferred because it offers high bit rates at low cost. Both services are delivered in the maximum allowed quality level.

4.2.5 Walking towards the office building

Mr. Green gets off the subway at the station nearest to his office. He starts walking towards the office building, while he continues to participate in the meeting. As he is not completely satisfied with the current quality level of the video call service, he modifies his profile, specifying quality level 5 as the maximum allowed for this service (instead of quality level 3).

IAS is triggered by the unavailability of access point WLAN #1, through which web browsing and video call are being delivered, and also by a change in the user profile.

Before the change in the user profile, IAS selects:

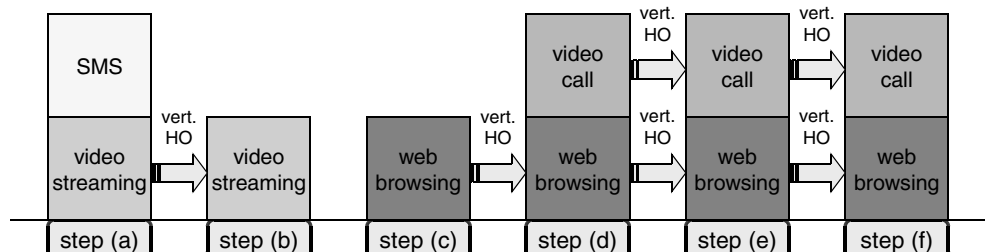
- GSM #4, web browsing, QoS-3 (125 ms)
- UMTS #3, video call, QoS-3 (47 ms)

Reason for this allocation: Web browsing is allocated to GSM #4 and to quality level 3, as this solution provides, for the specific service, the best combination of quality and cost. More specifically, in this case, the cost-effective quality level 3 which is offered by GSM #4 outranks the higher but more expensive quality level 4 that may be delivered through UMTS #3. On the other hand, UMTS #3 is selected for the video call service, as it provides better signal strength (and the cost is approximately the same, compared to GSM #4). Quality level 3 is at this time the maximum allowed for this service.

After the change in the user profile, IAS selects:

- GSM #4, web browsing, QoS-3
- UMTS #3, video call, QoS-5 (47 ms)

Figure 5 Seamless service provision in scenario steps



Reason for this allocation: Video call is now allocated to a higher quality level (level 5), in order to satisfy the new user preferences. This is the maximum quality level in which the video call service may be delivered, and it is the preferred choice as the user has specified ‘quality’ as the most important factor.

#### 4.2.6 Inside the office

Mr. Green arrives at the office. He heads quickly towards the meeting room and, as he enters, terminates the web browsing and the video call services.

IAS is triggered by the availability of new attachment points (WLAN #2, DVB #2). IAS selects:

- WLAN #2, web browsing, QoS-4 (156 ms)
- WLAN #2, video call, QoS-5 (109 ms)

Reason for this allocation: The appearance of new available attachment points leads to the reconsideration of the current allocations of services to networks and quality levels. WLAN technology is now preferred because it offers high bit rates at low cost. Both services are delivered in the maximum allowed quality level.

As may be observed, the IAS algorithm’s functionality within the framework of the scenario presented above, resulted in the provision of the requested services in a completely seamless way. More specifically, the transparent and uninterrupted delivery of the services that were considered was achieved through six vertical handovers: one for the video streaming service, three for the web browsing service and two for the video call service (Fig. 5). The algorithm’s good response time should also be noted, as it is an important factor in making handovers transparent to the user, in terms of service provision continuity.

## 5 Conclusion

This paper presented a management architecture that enables mobile terminals to operate in the beyond 3G context, while allowing users to benefit for the always best connected concept. It described the structure and functionality of a terminal management system (TMS) that incorporates functionality for retrieving and processing a minimal set of parameters based on which the terminal can perform intelligent access selection in a heterogeneous environment. It elaborated on the core functionality of each of the TMS’s main modules, namely the Network Interface Adaptation module, the User Preferences module and the Mobility Management module, and gave special focus to the Intelligent

Access Selection functionality incorporated in the latter module. This function is able to indicate the optimal allocation of services to network interfaces and quality levels in near real-time. The IAS problem was defined, mathematically formulated and solved. Results were presented in which the efficiency of the proposed solution in a realistic, everyday scenario was shown.

An interesting extension of this work involves the replacement of the graphical user interface through which the user specifies his preferences with a system that can autonomously and dynamically predict the user’s priorities, according to the usage context and the service that is being requested. Consequently, the allocation decisions that the IAS algorithm reaches based on these predictions may be submitted to the user for approval or rejection. A rejection from the user indicates that the system was wrong in its estimates of his preferences in the specific context, while an approval indicates that the system’s predictions were correct. This process allows the system to finally adapt to the user’s pattern of behaviour and to autonomously, from then on, handle all mobility events with minimal user interference.

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**Artemis A. Koutsorodi** was born in Athens, Greece, on May 8, 1979. She received her Dipl.-Ing. Degree from the School of Electrical and Computer Engineering of the National Technical University of Athens (NTUA) in 2002. In 2006 she received her Ph.D. in terminal management in the context of fourth generation systems from the same institution. She is currently a research associate in the

Computer Networks Laboratory of NTUA. Her primary research interests are wireless communication systems, network convergence, user profiling and user preference modeling. She has participated in several European Union and National research projects. She is a member of the Technical Chamber of Greece.



**Evgenia F. Adamopoulou** was born in Athens, Greece, on November 15, 1982. She received her Dipl.-Ing. degree from the School of Electrical and Computer Engineering of the National Technical University of Athens (NTUA) in 2005. She is currently working toward a Ph.D. degree at the same institution. Her research interests include wireless communications systems and telecommunications software design and implementation.



**Konstantinos P. Demestichas** was born in Athens, Greece, on May 19, 1982. He received his Dipl.-Ing. degree from the School of Electrical and Computer Engineering of the National Technical University of Athens (NTUA) in 2005. He is currently working toward a Ph.D. degree at the same institution. His research interests include wireless communications systems and telecommunications

software design and implementation.



**Michael E. Theologou** was born in Thessaloniki, Greece, in 1949. He received his degree in electrical engineering from Patras University in 1972 and his Ph.D. degree from the National Technical University of Athens (NTUA) in 1990. During 1972–1974 he worked in the Research Centre of the Greek Army. From 1975 to 1991 he worked as a Telecommunications Engineer in the Hellenic Telecommunications

Organisation (OTE), Department of Wireless Transmission. Since 1991 he has been with the National Technical University of Athens, where he is currently a Professor at the Department of Electrical Engineering, Division of Computer Science teaching and conducting research in the wider area of Telecommunication Systems. His research interests lie in the field of mobile and personal communications. He has numerous publications and has participated in various national and international projects. Prof. Theologou is a member of the Technical Chamber of Greece.