Intelligent Access Network Selection in Heterogeneous Networks

Simulation Results

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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

I. 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. 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 ([8]). 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 dynamically alter his preferences.

II. TERMINAL MANAGEMENT ARCHITECTURE

A. 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).
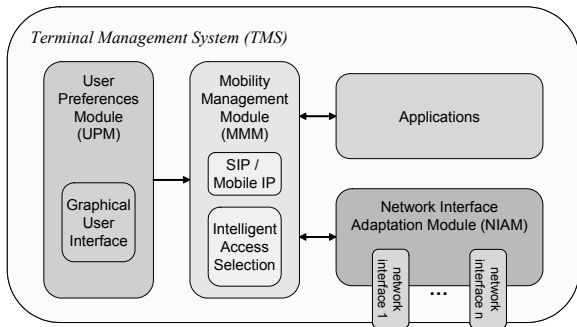
Figure 1. TMS Architecture

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.

B. Network Interface Adaptation Module

The NIAM is responsible for identifying the different interfaces present in the terminal, for monitoring their 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 and its network operator.

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 [9]) and for processing this information in order to detect if a new attachment point has appeared in the terminal's neighbourhood, or if the perceived signal strength from an already selected attachment point has severely deteriorated. In any of these cases, the MMM is notified accordingly for the purpose of triggering the process of optimally distributing all running applications to appropriate interfaces.

C. User Preferences Module

The UPM is responsible for storing, accessing and editing the user's profile. A graphical user interface (GUI) 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', preferred 'network operator', preferred 'technology type' and 'cost' 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 $w_q > w_t > w_c > w_o$.

D. Mobility Management Module

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 ([10]), while an IP mobility protocol such as Mobile IP ([11],[12]) provides an IP-layer solution for making movements on the IP layer transparent to higher protocol layers. Additionally, work is currently underway ([13],[14]) 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.

III. INTELLIGENT ACCESS SELECTION

The IAS function is triggered in the following cases: (a) when a new service request appears; (b) when the user changes his/her profile; (c) when the NIAM issues a notification of severe signal degradation; (d) when the availability of a new attachment point 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 Figure 2.
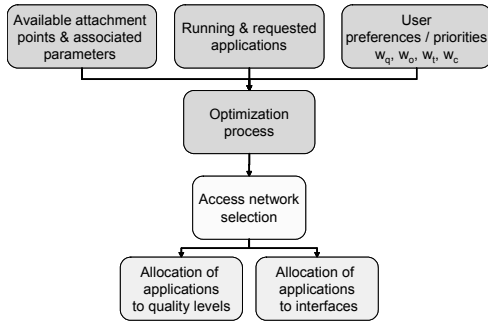
Figure 2. Intelligent Access Selection optimization process

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 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.

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, $P = \{p_1, p_2, ..., p_n\}, n \in \Box$, and $Q(p)$ the set of quality levels at which attachment point p can offer the service under consideration, $Q(p) = \{q_1, q_2, ...q_m\}, m \in \Box$. The goal is the computation of:

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

for all $p \in \text{P}$ and $q \in \text{Q}(p)$, and the determination of:

$\max\limits_{\forall p \in P} \left\{ \max\limits_{\forall q \in Q(p)} \left\{ OF(p,q) \right\} \right\}$ 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.

Factor $\text{Quality}(p,q)$ in (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. Coefficient $q_s(p)$ may be assigned values within the range from 0 to 1.

Factor $\text{Cost}(p,q)$ in (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 operator's 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. Kb) or per time unit (e.g. sec).

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, maxCost the maximum cost per unit for this specific service and 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 (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: $w_q \times \text{Quality}(p,q) - w_c \times \text{Cost}(p,q)$, and in the proposed implementation stands as follows:

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

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

A. Scenario Description

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. 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 QoS levels and through connections to the best available access networks (GSM, UMTS, WLAN, DVB).

The user profile in use during this time includes the following settings: 1.'cost'; 2.'quality'; 3.'network operator'; 4.'technology type'; hence, $w_c = 0.8$, $w_q = 0.6$, $w_o = 0.4$ and $w_t = 0.2$. Mr. Green has not specified any preferred choice, neither for 'network operator' nor for 'technology type'. Table I presents the maximum allowed quality levels for each service of the scenario, according to the user's settings.

TABLE I. AVAILABLE AND MAX QUALITY LEVELS FOR SERVICES IN SCENARIO

	SMS	video call	video streaming	web browsing
Total number of quality levels	1	5	5	5
Max allowed quality level	1	3	4	4

B. Results

In the lower part of Figure 3, a list of all available attachment points, during the course of the scenario, is presented. For each attachment point, the level if its signal level is shown. As may be observed, attachment point UMTS#2 belongs to network operator "Operator #3", while all other attachment points belong to other network operators. In the middle section of Figure 3, the computed allocation of services to appropriate quality levels and network interfaces is shown (the algorithm's execution time is also indicated within parentheses). In the upper section of Figure 3, the reason for triggering the IAS algorithm is noted.
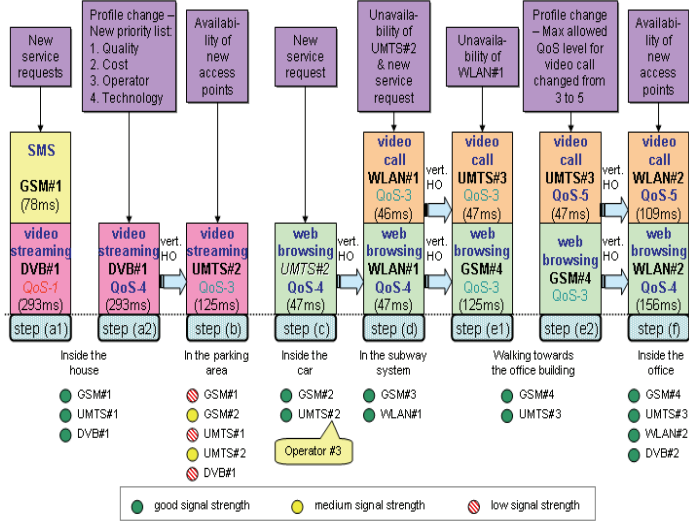

Figure 3. Seamless service provision in scenario steps

In the following paragraphs, a short description of each scenario step, as well as a detailed explanation of the corresponding allocation decisions, is given.

(a) *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 profile, specifying 'quality' as the most important factor and 'cost' as the second factor ($w_q = 0.8$, $w_c = 0.6$, $w_o = 0.4$, $w_t = 0.2$).

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

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

$$\text{Quality}(p_1, q_1) = q_s(p_1) \times q_1 = 1.0 \times 1 = 1,$$
$$\text{Operator}(p_1) = 0, \text{Technology}(p_1) = 0,$$

$$\text{Cost}(p_1, q_1) = \frac{\text{noQoSLevels}}{\text{maxCost}} \times \text{actualCost}(p_1, q_1)$$

$$= \frac{5}{0.95} \times 0.0085 \square\ 0.044737$$

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 $OF(p_1, q_1) > OF(p_i, q_j)$, $\forall\ i, j$, with $i \times j \neq 1$, $i \leq 3$, $j \leq 4$.

Sub-step (a1): 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.

Sub-step (a2): 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.

(b) *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.

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.

(c) 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.

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.

(d) 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.

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

(e) 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).

Sub-step (e1): 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.

Sub-step (e2): After the change in the user profile: 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.

(f) 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.

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.

V. CONCLUSION

This paper presented a management architecture that enables mobile terminals to operate in the beyond 3G context, while allowing users to benefit from 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.

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