# Service Configuration and Access Selection in 4G Terminals

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*Abstract*-**This paper proposes a management architecture for devices operating in heterogeneous environments, which incorporates intelligence for supporting mobility and roaming across legacy access networks. It focuses on the functionality of the proposed scheme that supports terminal-initiated and terminal-controlled access network selection. It discusses the decomposition of the proposed Terminal Management System into separate modules, responsible for retrieving link-layer measurements from available attachment points, 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 resource availability, user preferences and service requirements.**

## 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]), 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.

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 ([3]). 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 ([6]). 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).
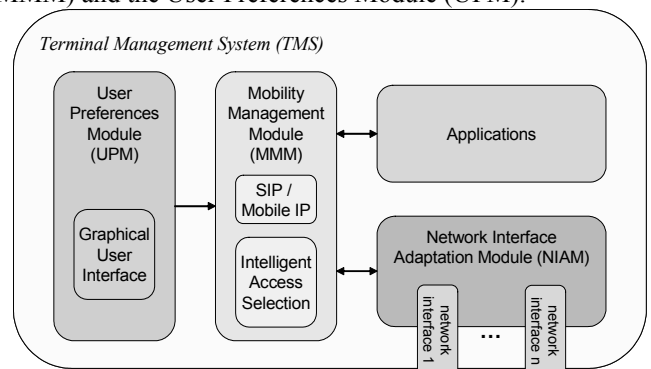


Figure 1. TMS Architecture

The following paragraphs discuss these modules in more detail.

### B. Network Interface Adaptation Module

The NIAM is responsible for providing the terminal

with a level of abstraction from the different network drivers. 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 [7]) 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 an appropriate decision algorithm for selecting the optimum available attachment point for each service.

More specifically, SIP may be used as an application layer protocol whose main functionalities are application level set-up and application level session management ([8]), while an IP mobility protocol such as Mobile IP ([9],[10]) may provide an IP-layer solution for making movements on the IP layer transparent to higher protocol layers. Additionally, work is currently underway ([11],[12]) to extend mobility protocols in order to allow

seamless IP handover. A pre-requisite for 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 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 requested and already running services to appropriate quality levels, and an optimal allocation of 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, $P = \{p_1, p_2, ..., p_n\}, n \in \mathbb{N}$ , and $Q(p)$ the set of quality levels at which attachment point $p$ can offer the service under consideration, $Q(p) = \{q_1, q_2, ...q_m\}, m \in \mathbb{N}$ . The goal is the computation of:

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

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

$\max_{\forall p \in P} \left\{ \max_{\forall q \in Q(p)} \left\{ OF(p,q) \right\} \right\}$ as the optimal attachment point

and quality level for each of the requested/running services.

In the proposed implementation, coefficients $w_i$ 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 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: 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 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 Cost$(p,q)$ to a scale that renders them comparable to the values of Quality$(p,q)$. Let 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, $\text{Cost}(p,q) = \dfrac{\text{noQoSLevels}}{\text{maxCost}} \times \text{actualCost}(p,q)$.

Finally, as far as the factors Operator$(p)$ and 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 difference: Quality$(p,q) - \text{Cost}(p,q)$, and stands as follows:

$$\text{Operator}(p) = \begin{cases} 0.5 \times \left[ \text{Quality}(p,q) - \text{Cost}(p,q) \right], & \text{if they match} \\ 0, & \text{otherwise} \end{cases}$$

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

## IV. IMPLEMENTATION AND EVALUATION

### A. Scenario description

The TMS discussed in this paper has been implemented as a Java-based middleware platform, targeted either for Sun's J2SE Virtual Machine v1.2 (or later) or for J2ME Wireless Toolkit v2.2. In the platform's current version, the NIAM periodically collects measurements, offline, from XML files that reflect network conditions in each step of the scenario that is executed. Scenarios may easily be edited and stored through a graphical user interface, as shown in Figure 2, and they consequently serve as input to the platform.

The scenario analyzed here simulates a typical day in the life of an ordinary user X, and is used to test the IAS algorithm's functionality. X commutes from his home to his office, using both his car and the subway. He exploits the time needed to reach his office by making use of several services via his B3G terminal.

The user profile in use during this time includes the following settings: 1.'quality'; 2.'cost'; 3.'network operator'; 4.'technology type'; hence, $w_c = 0.8$, $w_q = 0.6$, $w_o = 0.4$ and $w_t = 0.2$. X has specified "Oper #1" as his preferred 'network operator' and "WLAN" as his preferred 'technology type'.
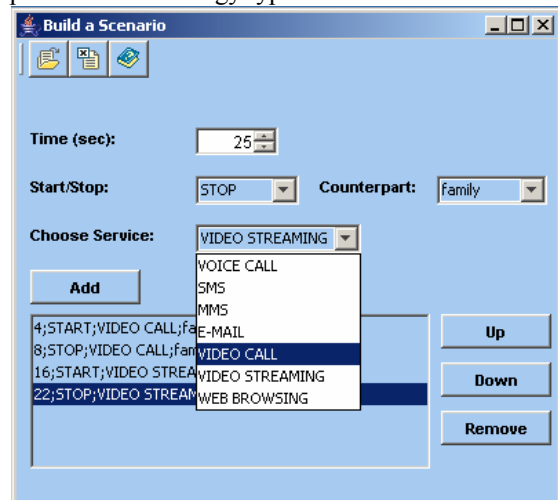


Figure 2. GUI of scenario builder

Available access points in each of the five scenario

steps, along with their bandwidth availability, signal strength and operator are shown in TABLE I.

| Scenario step | Available APs | | | |
|---|---|---|---|---|
| | AP name | Signal strength | Operator | Available bandwidth (kbps) |
| (a) *home* | GSM #1 | 5 | #2 | 44 |
| | UMTS #1 | 3 | #1 | 280 |
| | UMTS #2 | 2 | #3 | 180 |
| (b) *parking area* | GSM #1 | 3 | #2 | 44 |
| | UMTS #1 | 3 | #1 | 500 |
| | UMTS #2 | 3 | #3 | 1200 |
| | GSM #2 | 4 | #4 | 44 |
| (c) *car* | GSM #2 | 3 | #4 | 44 |
| | UMTS #2 | 5 | #3 | 1200 |
| (d) *subway* | UMTS #3 | 5 | #5 | 900 |
| | DVB #1 | 3 | #4 | 3000 |
| (e) *office* | WLAN #1 | 5 | #5 | 900 |
| | DVB #1 | 4 | #4 | 3000 |

In the following, a brief description of X's activities and service request in throughout the scenario is given.

*(a) Morning, at home:* As user X prepares to leave for work, he initiates a web browsing service and starts downloading a large file containing a financial report. He also initiates a video call session to a colleague at work.

*(b) In the parking area:* X leaves his house and heads towards the parking area, while the web browsing and video call sessions are ongoing. As he approaches the parking area, new attachment points become available, while the signal received from a previously available attachment point is getting weaker.

*(c) Inside the car:* X gets in his car and terminates the video call, while the web browsing session is still ongoing.

*(d) In the subway:* X arrives at the subway station. The download of the financial report from the web is still ongoing. As X realizes that he is running late for his morning meeting, he initiates a video streaming session, in order to participate in the meeting from the subway.

*(e) Inside the office:* X arrives at the office, while the web browsing and video streaming services are still running. As he enters the meeting room he terminates both services.

*B. Scenario execution*

In the framework of the scenario described above, the proposed IAS algorithm is compared to the simplest available and widely adopted scheme which favors the selection of a new access point whose signal strength indication surpasses the currently selected access point's signal strength indication by a certain threshold for a certain amount of time. This method shall be referred to as Best Signal Strength (BSS).

TABLE II depicts the service allocations (to access points and quality levels) computed by the IAS algorithm and by the BSS method, in each scenario step.

| Scenario step | Service | IAS | | BSS | |
|---|---|---|---|---|---|
| | | AP name | QoS level | AP name | QoS level |
| (a) *home* | Web Browsing | UMTS #1 | 3 | GSM #1 | 1 |
| | Video Call | UMTS #1 | 4 | GSM #1 | 1 |
| (b) *parking area* | Web Browsing | UMTS #1 | 4 | GSM #2 | 1 |
| | Video Call | UMTS #1 | 5 | GSM #2 | 1 |
| (c) *car* | Web Browsing | UMTS #2 | 5 | UMTS #2 | 5 |
| (d) *subway* | Web Browsing | UMTS #3 | 4 | GSM #2 | 4 |
| | Video Streaming | DVB #1 | 5 | GSM #2 | 3 |
| (e) *office* | Web Browsing | WLAN #1 | 4 | GSM #2 | 4 |
| | Video Streaming | DVB #1 | 5 | GSM #2 | 3 |

*C. Results - Discussion*

The chart depicted in Figure 3 refers to the web browsing service, which is ongoing in all scenario steps (1 through 5 on the x axis). The y axis represents the ratio $R$ of the aggregate quality to the aggregate number of handovers in each step. That is, we define:

$$R = \frac{QoS_{aggr.}}{\# HO_{aggr.}}$$ as an ascending function that favors high

quality service allocations and few handovers. For example, in step (b) of the scenario, the web browsing service continues to be served by the same UMTS access point as in step (a) and is assigned to quality level 4, when using the IAS algorithm. The BSS method hands this service over to another access point and assigns it to quality level 1. $R_{step(b) - IAS}$ and $R_{step(b) - BSS}$ are hence computed as follows:

$$R_{step(b) - IAS} = \frac{QoS_{step(a)} + QoS_{step(b)}}{1} = 7 \text{ and}$$

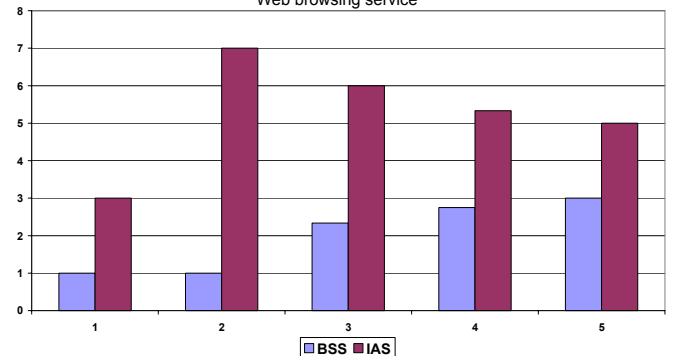$$R_{step(b) - BSS} = \frac{QoS_{step(a)} + QoS_{step(b)}}{2} = 1$$



Figure 3. Ratio of aggregate quality QoS to aggregate number of handovers, in scenario steps 1 to 5

The chart depicted in Figure 4 refers to the video call and video streaming services, which are ongoing in scenario steps 1 through 2 and 4 through 5 respectively. The y axis represents the utility volume $U$ of each allocation, computed both using the IAS algorithm and the BSS method. Utility is a term in economics, defined as the aggregate sum of satisfaction or benefit that the user gains (from each service configuration in our case). In fact, the objective function $OF(p,q)$ defined in section III may be interpreted as a measure of the user's benefit from each service allocation, and is used for computing utility volumes in each scenario step.
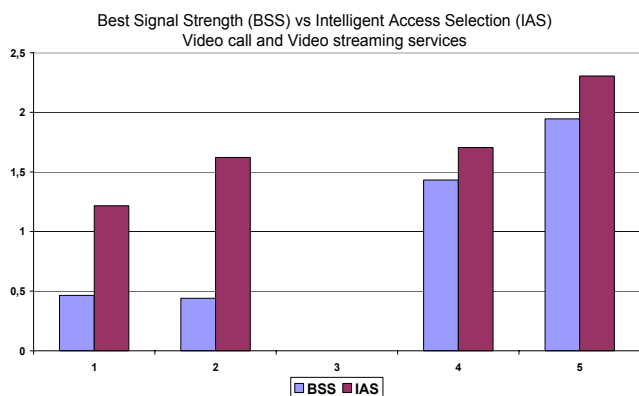


Figure 4. Utility computed for the voice call and video streaming services

The comparison depicted graphically in these charts renders apparent the benefits of using the IAS algorithm in service configuration and access selection: there is a clear trend in maximizing the overall level of quality delivered to the user and in raising the utility associated with service usage.

## V. Conclusion

This paper presented a management architecture that enables mobile terminals to operate efficiently in the beyond 3G context. It described the structure and functionality of a terminal management system (TMS) that incorporates functionality for 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 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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