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Research Article

An Intelligent Handover Management System for Future Generation Wireless Networks

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Future generation wireless networks should provide to mobile users the best connectivity to services anywhere at anytime. The most challenging problem is the seamless intersystem/vertical mobility across heterogeneous wireless networks. In order to answer it, a vertical handover management system is needed. In our paper, we propose an intelligent solution answering user requirements and ensuring service continuity. We focus on a vertical handover decision strategy based on the context-awareness concept. The given strategy chooses the appropriate time and the most suitable access network among those available to perform a handover. It uses advanced decision algorithms (for more efficiency and intelligence) and it is governed by handover policies as decision rules (for more flexibility and optimization). To maintain a seamless service continuity, handover execution is based on mobile IP functionalities. We study our decision system in a case of a 3G/UMTS-WLAN scenario and we discuss all the handover decision issues in our solution.

1. INTRODUCTION

The existence of various wireless technologies (3G/UMTS, WLAN, WMAN, etc.), with the evolution of multi-interface mobile terminals (MTs) and IP-based applications, has allowed a mobile user to have access to IP services anywhere at anytime from any network. This universal wireless access is driven by the future generation of wireless networks (FGWNs) (i.e., the 4th generation (4G) of wireless communications [1]). To ensure ubiquity and seamlessness challenges in FGWN, intersystem handover management is the essential issue that supports the moving of users from one wireless system to another during active communication.

In FGWN, the need for vertical handovers can be initiated for convenience (e.g., according to user choice for a particular service) rather than connectivity reasons (such as in horizontal handover). Vertical handover challenges are performance optimization (e.g., reducing overhead signaling, handover latency) and user requirements satisfaction. These particular requirements can refer to the *always best connected* (ABC) concept, of being connected in the best possible way in an environment of heterogeneous wireless networks [2]. For that, decision parameters have to be considered such as network conditions and user preferences. Thus, a vertical handover management solution can mostly concern the handover decision phase: the decision for the appropriate time to initiate the handover and for the most suitable access network from those available.

In this paper, we propose an *intelligent* handover management system controlled by the mobile. It applies the ABC concept that answers "if a handover is needed or not" (i.e., handover initiation) and "over which access network to handover" (i.e., network selection) while maintaining service continuity. The first choice can minimize, for instance, the signalling overhead and avoid unnecessary handovers. The second choice can satisfy network and user requirements. More precisely, we consider a *context-aware* vertical handover decision: multiple criteria are considered as contextual information gathered from terminal and network sides and advanced *decision algorithms* (for handover initiation and network selection) are needed. Moreover, we use vertical *handover policies* expressing rules that shape the handover decision process. The handover execution is based on mobile IP (MIP) functionalities for service continuity.

The handover decision scheme is studied under a 3G/UMTS-WLAN environment.

In our system, we provide a combination of interesting decision strategies [3–5]: a *context-aware* strategy for multiple criteria use and precision, advanced *decision algorithms* for efficiency and intelligence, and *policies* for flexibility and optimization. Thus, our approach should be conscious of all the contexts (access network availability, MT's movement, QoS parameters, etc.), takes the right decision at the right time (according to user objectives and handover policies), and ensures service continuity for the demanding service. This combination of a context-aware approach using policies can provide an efficient and optimized vertical handover decision solution. This latter can facilitate MIP-based procedures necessary for handover execution phase. With a mobile-controlled model, our approach can be a flexible handover management system for a 3G/UMTS-WLAN environment.

The paper is organized as follows. Section 2 presents the related work. Section 3 introduces the architecture of our handover management system. Section 4 describes the handover decision strategy. Section 5 gives the handover execution procedure. Section 6 studies a 3G/UMTS-WLAN scenario and discusses the proposed system features. Finally, Section 7 concludes our work.

2. RELATED WORK

The handover management remains a widely studied issue in the case of a heterogeneous environment. In FGWN, mobile users should be able to move among these heterogeneous networks in a seamless manner. Various activities of working groups are currently under way such as IEEE 802.21 [6], IETF MIP [7], or 3GPP standards [8]. IEEE 802.21 specifies media-independent handover (MIH) services and aims at providing link layer intelligence and other related network information to upper layers to optimize handovers between heterogeneous link layer technologies. IEEE 802.21 supports a mobile-controlled handover (MCHO) scheme and MIP as mobility management protocol. It is the MIH function that provides intelligence to the network selection entity or the mobility management entity responsible for handover decision based on L1, L2, and L2.5 triggers. The details of network selection entity and the specification of handover policies that control handovers are outside the scope of the 802.21.

The first vertical handover decision scheme, that considered multiple criteria user intervention and policies, was proposed by [3]. It introduced a cost function to select the best available access network based on three policy parameters (bandwidth, power consumption, and cost). Reference [9] proposed also a multiservice vertical handover decision algorithm cost function. However, the solution is based on a policy-based networking architecture (i.e., IETF framework). For more efficiency and taking into account more criteria, context-aware decision solution has inspired the authors in [5, 10, 11]. In [10], the authors designed a cross-layer architecture providing context-awareness, smart handover, and mobility control in a WWAN-WLAN environment. They proposed a vertical handover decision, with a cost function-based solution, taking into account network characteristics and higher level parameters from transport and application layers. References [5, 11] are based on a multiple criteria decision-making algorithm, analytic hierarchy process (AHP) [12]. Nevertheless, some information coming from the context (network or terminal) can present uncertainty or imprecision. Thus, more advanced multiple criteria decision algorithms are necessary to cope with this kind of information. To meet this requirement, in their work [4, 13], Chan et al. applied the concept of fuzzy logic (FL). They employ decision criteria such as user preferences, link quality, cost, or QoS. We compared in detail the different vertical handover decision strategies in [14].

In this paper, we design our decision strategy while taking advantage of the most interesting solutions and particularly the best aspect of each one. Our solution was introduced in [15]. It is based on context information as proposed in [5] and tools such as AHP and FL [4]. To deal with the decision problem complexity, our scheme is based on vertical handover policies that express rules to help managing the whole decision process. This combination can prepare also MIP procedures in handover execution for service continuity such as in [16].

3. THE HANDOVER MANAGEMENT SYSTEM

Figure 1 gives our proposed MT functional architecture containing the following given modules.

The *network interfaces* module contains the protocol stack of each network. These interfaces are monitored periodically and one of them will be intelligently selected and activated in the handover process.

The *handover management* module is responsible for providing transparent switching between networks. So, it encloses the main phases of a handover process.

(i) *Handover information gathering (HoIG)*. Collecting all the contextual information, through monitoring and measurements, required to identify the need for handover and to apply handover decision policies.

(ii) *Handover decision (HoD)*. Determining whether a handover is needed (i.e., *handover initiation*) and how to perform it by selecting the most suitable network (i.e., *network selection*) based on decision criteria.

(iii) *Handover execution (HoE)*. Establishing the IP connectivity through the target access network. This will implement protocols such as MIP.

The *upper layers* enable functionalities such as session management services to the application and provide additional information to the HoIG module.

In our paper, the handover criteria are the qualities measured to give an indication for a context-aware handover decision. It is required to be context-aware in the sense that it should be conscious of possibilities offered by each access network, MT's movements and QoS requirements for the demanding service. In traditional handover decision, only one criteria is used, the received signal strength (RSS). For a vertical handover decision, it is not sufficient. Context information is relevant in a way that they are useful enough to avoid false decisions, therefore, bad performances. They can be relative to the network, the terminal, the service, and the user. Here, we group it into two parts as in [5]: all the information related to the network on one side and all the information that may exist at the terminal on the other. There are the following contexts.

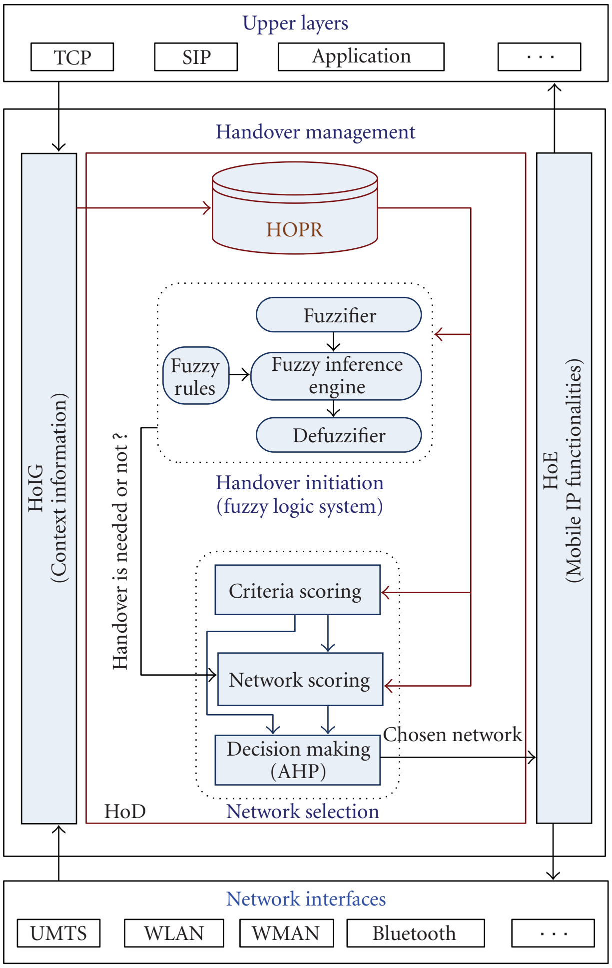
(i) *Network context.* QoS parameters (bandwidth, delay, jitter, packet loss), coverage, monetary cost, link quality as RSS, and bit error rate (BER) of the current access network and its neighbors.

(ii) *Terminal context.* User preferences, service capabilities (real-time and non-real-time), terminal status (battery and network interfaces), priority given to interfaces, location, and velocity.

These criteria can be classified into *static* and *dynamic*. Typically, static criteria are user preferences and the monetary cost, whereas the MT's velocity, RSS, and access network availability are dynamic criteria.

These contextual information is provided by the HoIG module. It is responsible to keep the *handover policies repository* (HoPR) entries up to date. These entries (static or dynamic) are needed as policy parameters to govern the choices in the whole decision process. HoPR stores a set of policies expressing decision rules based on different parameters. A policy rule is a group of if-then rules (if *condition* then *action*). Examples of rules are given in the description of the decision process (see Section 4.1).

This combination of a context-aware approach using policies can provide an efficient and flexible vertical handover decision solution. We give more flexibility in a way that the whole handover process is completely controlled by the mobile (MCHO). It reduces more the overall complexity in the network, the signaling overhead, and the handover latency than a mobile-assisted handover (MAHO). Most conducted experiments and publications in vertical handovers [4, 5], even regarding policies, promote an MCHO decision model in which the MT is responsible for making decisions and to put all the intelligence at the MT. Therefore, we prefer an MCHO solution with respect to transfer of handover decision criteria and more precisely regrouping context information. Thus, MT conducts the initiation (at the decision phase) and the control of the handover (at the execution phase). Otherwise, MCHO does not exclude the assistance from the network in a way that it needs information, such as capabilities or bandwidth, to choose the most optimal network among those available. Moreover, this proves the distribution of computation between MTs compared to a centralized approach (a network-controlled handover, NCHO).



HoIG: Handover information gathering
HoPR: Handover policies repository
HoD: Handover decision
HoE: Handover execution

Figure 1: Our handover management system architecture.

4. THE HANDOVER DECISION STRATEGY

In heterogeneous environment, the handover decision process is very complex: decision criteria, coming from different sources, should be compared and combined to select the appropriate moment to handover and the target access network according to user preferences. Moreover, the gathered contextual information can be imprecise: unavailable or incomplete [17]. This complexity can be solved by using advanced decision algorithms applicable on multiple criteria and reasonable handover policies. In this section, we describe our intelligent vertical handover decision process based on two main phases: *handover initiation* and *network selection*. It is performed as a context-aware decision making problem, so a typical multiple criteria decision making (MCDM) problem. In the study of decision making, terms such as multiple objective, multiple attribute, and multiple criteria are often used interchangeably [17]. MCDM is sometimes applied to decisions involving multiple objectives or multiple attributes, but generally they both apply. Multiple objective decision making (MODM) consists of a set of conflicting goals that cannot be achieved simultaneously. Multiple attribute decision making (MADM) deals with the problem of choosing an alternative from a set of alternatives which are characterized in terms of their attributes.

In our process, we use FL and AHP as decision support tools. The use of fuzzy logic (FL) does not only combine and evaluate multiple criteria simultaneously, but also copes with imprecision and nonstatistical uncertainty. Hence, fuzzy logic (FL) concept provides a robust mathematical framework. It can be used to model nonlinear functions with arbitrary complexity. AHP is able to identify the decision problem as a multilevel hierarchical structure of primary objectives (i.e., according to user preferences) and decision criteria (i.e., context information). In the following subsections, our decision problem can be identified as a fuzzy or a classical MCDM problem.

4.1. *The decision process*

As previously mentioned, the handover management process, more detailed in Figure 2, starts with the *HoIG* phase. This latter gets context information through monitoring, measurements, or probing and updates *HoPR* permanently. The information gathered is needed to perform *handover initiation* described in Section 4.2 and *network selection* described in Section 4.3. At the terminal context level, the interfaces are monitored (L2 and L3 monitoring) to reach access networks, and the user preferences are defined to get objectives. At the network context level, QoS parameters or cost can be advertised by the available access networks. The HoIG module provides policy parameters to the HoPR such as network availability or user preferences. These parameters are retrieved by handover decision components when necessary and used to apply policy rules. The decision policy rules translate scenarios related to connectivity, network availability, user, or even corporate preferences. Our policy rules are as follows.

Policy Rule 1

Condition 1: an application is initialized,

Action 1: searching for the available networks to which the user can connect.

(evaluatin $\text{Number}_{\text{Network Availability}}$)

Policy Rule 2

Condition 2: only one available network,

($\text{Number}_{\text{Network Availability}} = 1$)

Action 2: enabling the *handover initiation* module.

- *Subcondition 1:* “handover is needed?” = YES,
- *Subaction 1:* Searching for new networks. (re-evaluating $\text{Number}_{\text{Network Availability}}$)

Policy Rule 3

Condition 3: more than one available network (overlapping coverage),

($\text{Number}_{\text{Network Availability}} > 1$)

Action 3: enabling the *Handover Initiation* module (for each network).

- *Subcondition 1:* “handover is needed?” = NO (for each network),
- *Subaction 1:* enabling the *network selection* module.

According to the flowchart in Figure 2, handover initiation evaluates current network conditions in order to decide if a handover is necessary. If it does not, there is no need to search for new available access networks. When MT is under an overlapping coverage, available network conditions must be satisfactory in order to enable network selection. *Criteria scoring* is a preconfiguration phase performed once HoIG gets user defined preferences. *Network scoring* is invoked for each service-type currently running in the terminal. Thanks to criteria scoring and network scoring results, *decision making* selects the most appropriate access network according to user preferences. Once the target access network chosen, a *HoE* can be performed (Section 5). We illustrate handover decision functioning in a 3G/UMTS-WLAN case of study in Section 6.

4.2. *Handover initiation*

The handover initiation phase is performed by a fuzzy logic system (FLS)with a *Mamdani fuzzy inference system (FIS)* as described in [4] (see the appendix). This phase is considered as a fuzzy MADM [17]. The information gathered (RSS, bandwidth, network coverage, velocity) depending on their availability are fed into a fuzzifier in which are converted into fuzzy sets. A fuzzy set contains varying degree of membership in a set. The membership values are obtained by mapping the values retrieved for a particular variable into a membership function. Figure 3 gives membership functions of the input fuzzy variables.

(i) The input fuzzy variable “RSS” has three fuzzy sets: weak, normal, and strong (Figure 3(a)).

(ii) The input fuzzy variable “bandwidth” has three fuzzy sets: low, normal, and high (Figure 3(b)).

(iii) The input fuzzy variable “network coverage” has three fuzzy sets: bad, normal, and good (Figure 3(c)).

(iv) The input fuzzy variable “velocity” has three fuzzy sets: slow, normal, and fast (Figure 3(d)).

These inputs are chosen answering specific needs related to different scenarios. RSS indicates the current radio link quality and acts as a pretreatment that helps to decide whether to trigger the handover. The bandwidth is different from a network to another (e.g., 3G/UMTS has lower bandwidth compared to WLAN). The velocity is also a very important criterion since when the coverage is bad, a high-speed MT would quickly pass through it. This can avoid excessive unnecessary handovers.

After fuzzification, fuzzy sets are fed into an inference engine, where a set of fuzzy rules are applied to determine

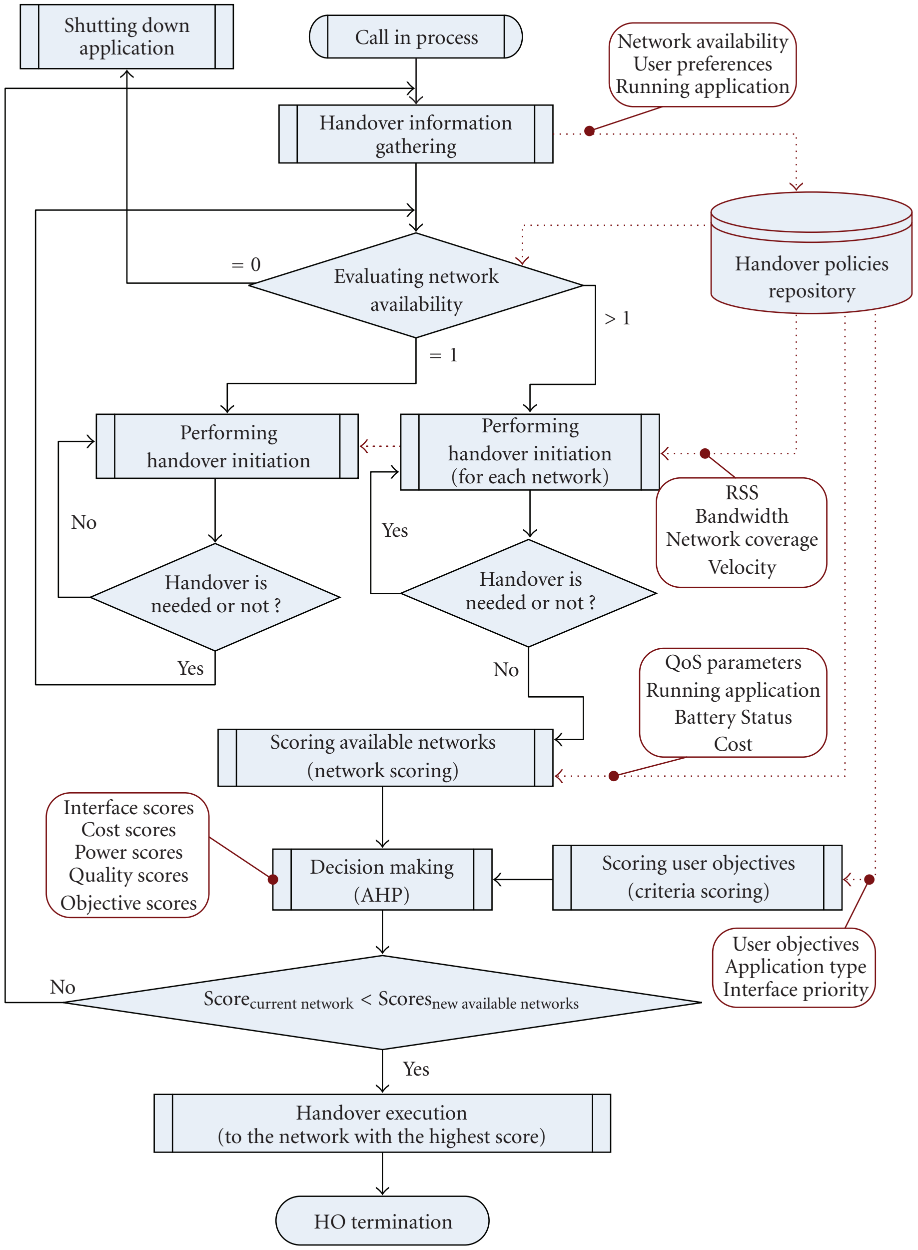
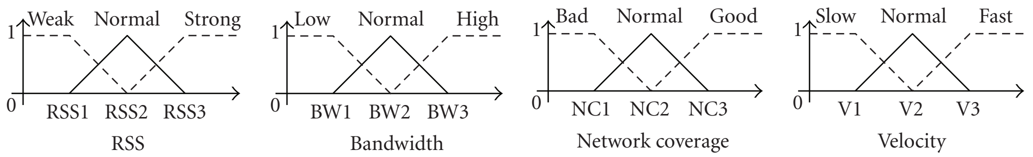


FIGURE 2: Handover decision process in our handover management system.



(a) Membership Function of "RSS"

(b) Membership Function of "Bandwidth"

(c) Membership Function of "Network Coverage"

(d) Membership Function of "Velocity"

FIGURE 3: Membership functions of fuzzy logic system (FLS).

Table 1: Examples of fuzzy rules.

Rule	RSS	Bandwidth	Network coverage	Velocity	HO is needed?
1	Weak	Low	Bad	Slow	YES
. . .	. . .	. . .	. . .	. . .	. . .
58	Strong	Low	Normal	Slow	Probably YES
. . .	. . .	. . .	. . .	. . .	. . .
69	Strong	Normal	Normal	Fast	Probably NO
. . .	. . .	. . .	. . .	. . .	. . .
81	Strong	High	Large	Fast	NO

whether handover is necessary (see Table 1). Fuzzy rules utilize a set of IF-THEN rules and the result is YES, Probably YES, Probably NO, or NO. As an example from Table 1, the rule 81 represents the case of an MT under 3G/UMTS coverage and should not handover to WLAN because of its velocity, in a 3G/UMTS-WLAN scenario. At the final step, the resultant decision sets have to be converted into a precise quantity. For that, centroid defuzzification method [4] is used to obtain a handover initiation factor (see the appendix). If this quantity is below a certain threshold (e.g., 0.85), a handover is needed.

4.3. Network selection

In this phase, we need more decision criteria from the terminal side (i.e., user preferences, service capabilities, battery status, and network interfaces) as well as from the network side (i.e., QoS parameters, cost). The most appropriate access network, from those available, has to be selected satisfying a number of objectives. So, we consider an MODM in which all alternatives available (access networks) are evaluated according to these objectives: *low cost*, the *preferred interface*, the *good battery status,* and to the *good quality (maximizing bandwidth, minimizing delay, Jitter, and BER)*. It is pointed out that contextual data can be crisp or fuzzy. Fuzzy data have to be converted to crisp numbers using conversion scales. Thus, a classical MODM such as AHP (see the appendix) is used to assign scores to the available networks.

As mentioned previously, before using AHP method directly, two steps have to be performed: the *criteria scoring*, a preconfiguration step, in which the importance of each objective is evaluated according to user preferences; and the *network scoring,* in which the available networks are evaluated and compared according to each objective.

(a) *Criteria scoring* is in charge of mapping priorities given by the user into scores. In our decision process, we consider two categories of services: *real-time* (voice, video conferencing or streaming, etc.) and *non real-time* (file transfer, email, web browsing, etc.). For each type of service, priorities are considered among the available interfaces in the MT (WLAN, UMTS, Bluetooth, etc.) and among the user preferences previously fixed. For example, the priority can be set to provide the fastest network connection to the mobile user, or the cheapest. WLAN interface can be set as high priority or alternatively chosen when a video application is active. Whereas, 3G interface can be set as high priority especially for voice application due to the almost 3G ubiquitous coverage. We obtain the following scores: *interface scores* and *objective scores*. Based on the priorities given by the user, scores between 1 and 9 are assigned automatically, where 1 is the most preferred one and 9 the least preferred one [5]. The scores are equal-spaced integers whose space gap is defined by (1), where N_p is the number of parameters, S_h and S_l are the highest and the lowest possible scores (i.e., 9 and 1), respectively, and I is the numeric space gap between two subsequent scores, which is rounded off to the nearest integer:

$$I = \frac{S_h - S_l}{N_p}. \tag{1}$$

For example, for *objective scores*, the user sets this order to the objectives: *preferred interface* (obj1), *low cost* (obj2), *good quality* (obj3), and finally *good battery status* (obj4). Here, (1) results in $I = 2$, while $S_h = 9$, $S_l = 1$, and $N_p = 4$. Obj1, obj2, obj3, and obj4 get scores of 1, 3, 5, and 7, respectively. The same measure is made for *interface scores*.

(b) *Network scoring* performs real-time calculations for each type of *running application*. Here, scores have to be assigned to each of the *available networks* based on user preferences. It is simple to get the network scores related to the interface and the cost. The same interface score, defined in the previous step, is assigned to the available network. For the cost and battery status objective, all the available networks are compared with each other. *Cost scores* and *power scores* are assigned using the equal-spaced scores between 1 and 9 based on (1) in a descending order, where the cheapest network has a score of 1. In the case of the quality objective, network QoS parameters are very dynamic and each application type has its own QoS requirements. So, we have to express QoS preferences as limits in order to compare them easily with the network QoS parameters. For that, we use a technique of mapping the four quality parameters (bandwidth, delay, jitter, and BER) into limits values (upper and lower), described in [5]. It is an easy and fast solution for comparing dynamic parameters for each demanding service. Now, we can compare the QoS parameters of all available networks with these values.

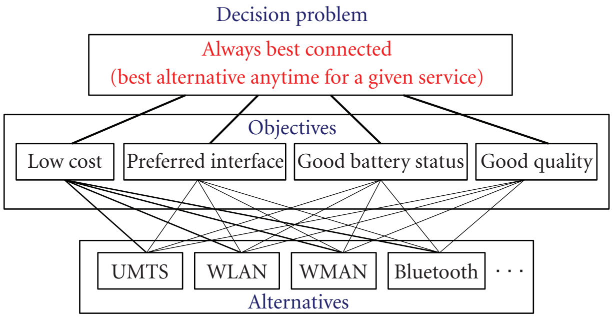


FIGURE 4: Decision making concept.

Quality scores are calculated as follows:

$$\begin{aligned} S_i &= \left(1 - \frac{n_i - l_i}{u_i - l_i}\right) \times 10, \quad l_i < n_i < u_i, \\ S_i &= 1, \quad n_i \geq u_i, \\ S_i &= 9, \quad n_i \leq l_i, \end{aligned} \tag{2}$$

$$\begin{aligned} S_i &= \left(\frac{n_i - l_i}{u_i - l_i}\right) \times 10, \quad l_i < n_i < u_i, \\ S_i &= 1, \quad n_i \geq u_i, \\ S_i &= 9, \quad n_i \leq l_i, \end{aligned} \tag{3}$$

where u_i and l_i are, respectively, upper and lower limits for a particular QoS parameter, and n_i is the value offered by a network for that parameter. However, (2) is specific to the bandwidth parameter, where the result is preferred to be as high as possible. Whereas, (3) is specific to delay, jitter, and BER parameters, where the result is preferred to be as low as possible.

(c) *Decision making* is the final step of the network selection phase and calculates the final decision once every parameter is available. The analytic hierarchy process (AHP) method is employed [12]. Our decision problem is structured as a hierarchy in which decision factors are identified and inserted. Figure 4 presents our decision concept with ABC as the overall objective (topmost node of the hierarchy), objectives as subsequent nodes, and solution alternatives as bottom nodes. AHP method is chosen due to its ability to vary its weighting between each objective. The AHP calculation is a three step process as follows.

(1) Calculating the *objective priorities or weights* from the objective pairwise comparison matrix A (4) based on *objective scores*:

$$A = \begin{pmatrix} 1 & \mathrm{RS}_{12} & \mathrm{RS}_{13} & \mathrm{RS}_{14} \\ \dfrac{1}{\mathrm{RS}_{12}} & 1 & \mathrm{RS}_{23} & \mathrm{RS}_{24} \\ \dfrac{1}{\mathrm{RS}_{13}} & \dfrac{1}{\mathrm{RS}_{23}} & 1 & \mathrm{RS}_{24} \\ \dfrac{1}{\mathrm{RS}_{14}} & \dfrac{1}{\mathrm{RS}_{24}} & \dfrac{1}{\mathrm{RS}_{34}} & 1 \end{pmatrix}, \tag{4}$$

where RS_{ij} values are the relative scores involved in each objective, indicating how much more important objective i is than objective j ((5), [5]):

$$\begin{aligned} \frac{1}{\mathrm{RS}_{ij}} &= \left(1 - \frac{S_j}{S_i}\right) \times 10, \quad S_i > S_j, \\ \mathrm{RS}_{ij} &= \left(1 - \frac{S_i}{S_j}\right) \times 10, \quad S_i < S_j, \\ \mathrm{RS}_{ij} &= 1, \quad S_i = S_j. \end{aligned} \tag{5}$$

A_{norm} (see the appendix) is the normalized matrix of A (6), where the values a_{ij} of each row for objective i are calculated to give priorities for each objective: wo_1 for obj1, wo_2 for obj2, wo_3 for obj3, and wo_4 for obj4 (7):

$$A_{\text{norm}} = \begin{pmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{pmatrix}, \tag{6}$$

$$wo_i = \frac{a_{i1} + a_{i2} + a_{i3} + a_{i4}}{4}. \tag{7}$$

(2) Calculating the *network weights* with respect to each objective through a network pairwise comparison matrix (8):

$$\begin{array}{ccc} & \text{Network1} & \text{Network2} \\ \text{Network1} & 1 & \mathrm{RS}_{12} \\ \text{Network2} & \dfrac{1}{\mathrm{RS}_{12}} & 1 \end{array}, \tag{8}$$

where RS_{ij} values are the relative scores among the scores of the available networks obtained at the *network scoring* step in terms of individual objective. After normalizing (8), we can calculate network weights wn_{ij}, where i and j represent, respectively, the available network and the specific objective, using (8).

(3) Determining the sum of products of objective weights (from step (1)) and network weights for each network (from step (2)) and selects the network with the highest sum. For i number of available networks and j number of objectives, the overall score is obtained from (9):

$$\text{Score}_{\text{Network}_i} = \sum_{1}^{ij} wn_{ij}(wo_j). \tag{9}$$

5. THE HANDOVER EXECUTION PROCEDURE

In order to maintain user sessions while moving between two networks, intersystem mobility solution is needed. For that, MIP [7] is an efficient IP layer mobility management

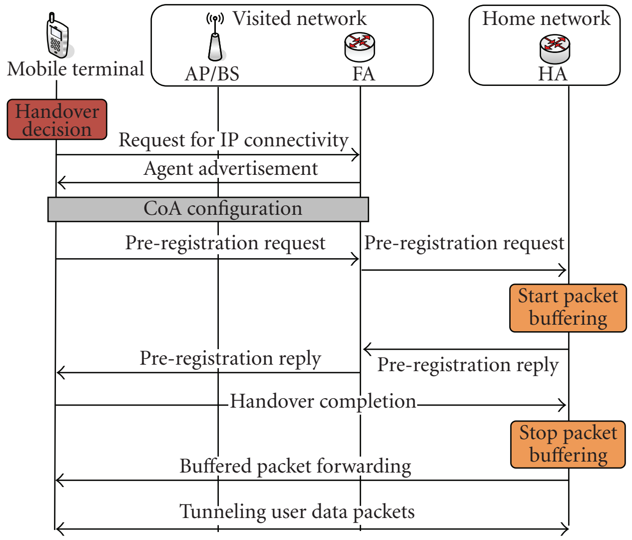
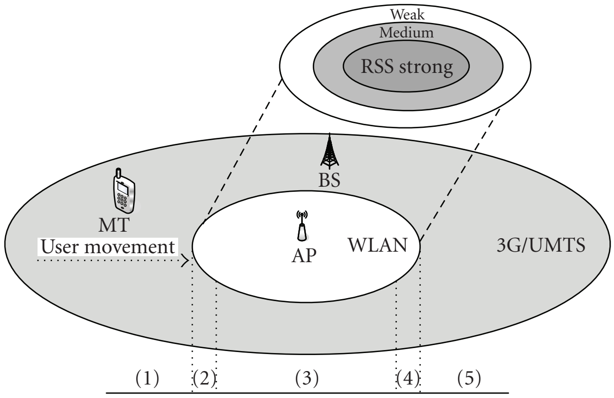


Figure 5: Generic MIP signaling for handover execution procedure.



MT: Mobile terminal
Ap: Access point
BS: Base station

Figure 6: 3G/UMTS-WLAN environment scenario.

presented in [14]. It requires to implement MIP functionalities with these components: home agents (HAs) and foreign agents (FAs) in both networks, and MIP support in the MT. MIP agents, installed in gateway routers, can help them to tunnel and forward the data packets. HA may be local to any network (i.e., depending on which network the user is subscribed to), it must be accessible by both networks to maintain current MT's location.

In order to maintain seamless service continuity, we focus on handover decision and execution strategies. In our scheme, the handover decision process plays an important role in handover execution process preparation. It is particularly useful under any overlapped coverage (e.g., 3G/UMTS and WLAN). When MT is moving out of a network coverage area, the proposed scheme can predict disconnections and, thus, saves the MIP movement detection and triggers preregistration. A generic MIP signaling for the handover execution procedure is depicted at Figure 5 (foreign network can be 3G or WLAN). Once handover decision is taken, IP connectivity has to be maintained. In MIP procedure, each MT is assigned to a pair of addresses: a home address and a temporary address called care-of-address (CoA) when away from its home network. The CoA in our solution is the address of the FA. So, we opt for MIPv4 because of its wide support by network operators today compared to MIPv6. Here, the important thing is that the use of standard MIP can drive to a nonseamless handover (significant handover latency for real-time services). Nevertheless, in order to remedy this problem, we use preregistration process to reduce the handover latency and packet buffering and forwarding functions thus reducing the packet loss [16].

Once handover decision taken, MT will request IP connectivity in order to obtain a CoA. The latter will be configured upon receiving the FA advertisements. After that, the MT can send an MIP *preregistration request* to the FA. This latter forwards the request to the HA. Right after, the HA creates a mobility binding between the MN home address and its CoA and sends a *preregistration reply*. Once received, FA forwards the reply to the MT. This preprocedure is finished when MT received a preregistration reply before L2 handover. Thus, a tunneling is established between HA and FA encapsulating packets received at the user home network, then forwarding them to its CoA. Moreover, to prevent packet loss, HA buffers packets destined to MT when receive the preregistration reply. It allocates extra space to store the MTs next CoA in the address table. Thus, after L2 handover completion, it updates this table by replacing the current CoA with the next one and forwards the buffered packets.

6. CASE OF STUDY: 3G/UMTS-WLAN ENVIRONMENT

In order to compare to other proposed solutions [9, 10], we choose a 3G/UMTS-WLAN environment to evaluate our handover decision strategy. 3G/UMTS offers wide area coverage with lower data rates and a higher cost than WLAN which offers higher data rates for less expensive cost, but in localized areas.

6.1. 3G/UMTS-WLAN scenario

In Figure 6, we give our 3G/UMTS-WLAN scenario. Our scenario can be divided into different phases according to MT movement (shown in the figure). We consider that a user moves with a certain velocity and he stops for a predefined pause time and then moves again (e.g., random waypoint mobility model). For RSS values, we assume that a coverage area is divided into three different regions: the darker one has the strongest RSS, the second one has lower RSS than the first one, and the third one has the weakest RSS. The last one is potentially the vertical handover area. It is pointed out that in real WLAN environment, RSS can highly vary over time even at a fixed location depending on parameters such as interference, user number in the area. We enumerate the different phases that could characterize the scenario as follows.

Table 2: Criteria and network scoring.

Voice application		Data application	
Objective scores			
1/Quality	1	1/Cost	1
2/Cost	3	2/Quality	3
3/Power	5	3/Power	5
4/Interface	7	4/Interface	7
Interface scores			
1/UMTS	1	1/WLAN	1
2/WLAN	5	2/UMTS	5
Cost scores			
1/WLAN	1	1/WLAN	1
2/UMTS	5	2/UMTS	5
Power scores			
1/UMTS	1	1/UMTS	1
2/WLAN	5	2/WLAN	5
Quality scores			
1/WLAN	1	1/WLAN	1
2/UMTS	5	2/UMTS	5

Table 3: Objective and network pairwise comparison matrix in AHP method.

(a)

Objective pairwise comparison matrix				
Normalized matrix				
Voice	Interface	Cost	Power	Quality
Interface	0.108	0.0213	0.0411	0.0739
Cost	0.324	0.5675	0.329	0.5916
Power	0.162	0.1419	0.0822	0.493
Quality	0.9258	0.8108	0.9399	0.6337
Normalized matrix				
Date	Interface	Cost	Power	Quality
Interface	0.0932	0.1138	0.0389	0.0259
Cost	0.7982	0.9751	0.8882	0.9879
Power	0.2661	0.1219	0.1110	0.037
Quality	0.5323	0.1463	0.4441	0.1482

(b)

Network pairwise comparison matrix		
Normalized matrix (voice)		
Interface	WLAN	UMTS
WLAN	0.124	0.124
UMTS	0.9923	0.9923
Cost	WLAN	UMTS
WLAN	0.9923	0.9923
UMTS	0.124	0.124
Power	WLAN	UMTS
WLAN	0.124	0.124
UMTS	0.9923	0.9923
Quality	WLAN	UMTS
WLAN	0.9923	0.9923
UMTS	0.124	0.124

(1) MT is under 3G/UMTS coverage area, it is associated to BS.

(2) MT is entering a WLAN coverage area. A 3G/UMTS-WLAN handover can be performed according to user objectives and the running application thanks to the network selection module that is performed when more than one access network is available. Thus MT is associated to AP. Otherwise, such a handover could not happen depending on the MT velocity (really fast) according to the handover initiation (FLS) result.

(3) MT is under a overlapping coverage. MT is associated to the most suitable access network answering its requirements. A handover could not be performed if the MT remains motionless for the same running application. After a certain period, network conditions can change (bandwidth is low). In this case, a handover could be performed.

(4) MT is leaving the WLAN coverage area (RSS is weak). This step is time critical, since the active connection would break if the WLAN coverage ended before performing the handover to 3G/UMTS. Thus the handover initiation module can predict MT disconnection and prepares the WLAN-3G/UMTS handover.

(5) MT is associated to BS of 3G/UMTS network.

6.2. Handover decision strategy evaluation

To study this environment of two access networks, we choose voice and data applications. The mobile user has MT with two interfaces: 3G/UMTS and WLAN. He enters his preferences for both applications. As mentioned in Section 4.3, the objectives are: *low cost* (cost), the *preferred interface* (interface), the *good battery status* (power), and the *good quality (maximizing bandwidth, minimizing delay, jitter, and BER)*. To simplify, the objective good quality takes into account only the bandwidth parameter. Here, we develop all the calculation steps of network selection for both applications. In Table 2, we give an example of results of the criteria and network scoring steps. For criteria scoring, we obtain interface and objective scores thanks to (1). After criteria scoring, we assume that the two networks are available and their current conditions are good (a handover is not needed). Thus we proceed to network scoring. We obtain cost scores, power scores, and quality scores thanks to (1) and (2).

In the decision making step with AHP method, we have to establish the objective pairwise comparison matrix. Following (4) with values calculated in (5), we obtain the normalized matrix in Table 3 from (6). The weights for each objective based on (7) are calculated: $wo_{\text{Interface}} = 0.0611$, $wo_{\text{Cost}} = 0.453$, $wo_{\text{Power}} = 0.2198$, $wo_{\text{Quality}} = 0.8276$ for voice application and $wo_{\text{Interface}} = 0.0679$, $wo_{\text{Cost}} = 0.9123$, $wo_{\text{Power}} = 0.1340$, $wo_{\text{Quality}} = 0.3177$ for data application.

Table 4: Network selection results.

Scenario	(1)	(2)	(3)	(4)	(5)
Available networks	3G/UMTS	WLAN 3G/UMTS	WLAN 3G/UMTS	WLAN 3G/UMTS	3G/UMTS
Our network selection algorithm					
Voice	3G/UMTS	3G/UMTS	3G/UMTS	3G/UMTS	3G/UMTS
Data	3G/UMTS	3G/UMTS	WLAN	WLAN	3G/UMTS
RSS-based algorithm					
Voice	3G/UMTS	3G/UMTS	WLAN	3G/UMTS	3G/UMTS
Data	3G/UMTS	3G/UMTS	WLAN	3G/UMTS	3G/UMTS

In the next step of the AHP method, we calculate the network weights with respect to each objective. We obtain the network pairwise comparison matrix (8) given in Table 3 in the normalized form for voice application. The network pairwise comparison matrix for data application is similar to voice application one. The only difference is the interface matrix. Here, we can have the values for the interface objective, for example, $wn_{\text{WLAN,Interface}} = 0.124$ and $wn_{\text{UMTS,Interface}} = 0.9923$ for voice application.

At the final step, we calculate the sum of products of objective weights and network weights for each network from (9). The results for the two available networks are $\text{Score}_{\text{WLAN}} = 0.3056$, $\text{Score}_{\text{UMTS}} = 0.4375$ for voice application and $\text{Score}_{\text{WLAN}} = 0.522$, $\text{Score}_{\text{UMTS}} = 0.3529$ for data application. The network with the highest score, UMTS, is finally selected for voice application and WLAN for data application.

According to the different phases of the scenario enumerated previously, we give the results for both applications of our solution compared to an RSS-based algorithm [15] in Table 4.

6.3. *Discussion*

As mentioned in Section 2, various handover decision strategies were proposed in FGWN. Compared to [9] that use a formula-based solution with optimizations, we use an inference-based one for handover initiation and a classical MCDM method for network selection. However, both answer user requirements (i.e., network selection) as well as network efficiency (i.e., handover initiation). Deciding for the correct time to initiate a vertical handover can reduce the subsequent handovers (i.e., ping-pong effect) and limit the signalling messages and can also predict disconnections during MT's movement. Thus handover latency can be reduced. Selecting the best access network can satisfy user requirements anywhere and anytime in a flexible (using policies) and efficient (AHP method) manner.

Otherwise, we have to discuss some relevant aspects that characterize or not our system.

(i) In our handover decision mechanism, the chosen decision techniques use complex calculations (fuzzy logic) on one hand, and simple calculations (AHP method), on the other hand. Thus we bring more intelligence and precision instead of *ease of calculation* (cost function) in the whole process for practical mobile terminals.

(ii) When MT tries to search for available access networks, it must activate the interfaces. The simplest way to discover these networks is always keeping all the interfaces on. However, activating the interface consumes battery power. A faster system discovery time is also desired because the MT can benefit faster from the new wireless network. Since our system based on handover decision policies is flexible, it is possible to add some specific rules as defined in [18] for a power saving *interface management* solution.

(iii) Periodically, the system reevaluates handover initiation when the mobile user is using a current access network. In a case where a handover is needed and there is no better access network available for the ongoing application, we are facing a problem of subsequent unnecessary handovers. To solve it, we can use a waiting period in which the stability aspect is maintained. Moreover, the *handover synchronization problem*, as mentioned in [3], considers that several MTs could discover the same better network and switch to it simultaneously. In this case, it causes instability for all these MTs and poor performance. For that, a randomized stability period is used.

(iv) It is pointed out that the MIP protocol is not relevant for delay-sensitive applications. With a handover decision mechanism that enables a preregistration, MIP movement detection time is saved. Thus it prepares the handover execution phase and participate to a seamless handover (minimum handover latency and packet loss). However, we are evaluating the *handover execution* module in an ongoing work.

7. CONCLUSION

In our paper, we propose a handover management system for future generation wireless networks. Our solution focuses on the handover decision process providing flexibility and efficiency thanks to advanced multiple criteria decision algorithms (fuzzy logic and AHP) and policies governing it. We give more flexibility in a way that the scheme is controlled by the mobile (MCHO). Thus it can provide performance optimization and prepare the handover execution phase. In a near future, we compare our handover management system with other existing techniques and we study the multiservice aspect such as in [9], since the proposed handover decision mechanism performs for one service at a time. Moreover, our vertical handover decision scheme can be applied to other environments such as 3G-WMAN and WMAN-WLAN, while proving seamless mobility.

APPENDIX

Mamdani fuzzy inference system

This method is the most commonly seen fuzzy methodology. The system essentially defines a nonlinear mapping of the input data into an output, using fuzzy rules. The mapping process involves input/output membership functions, FL operators, fuzzy if then rules, aggregation of output sets, and defuzzification. The fuzzy inference system contains four components: the fuzzifier, the inference engine, the fuzzy rule base, and the defuzzifier. The most popular defuzzification method is the centroid calculation.

In centroid defuzzification method

The defuzzifier determines the center of area (centroid y') under the curve given by

$$y' = \frac{\sum_{i=1}^{n} y_i \mu_B(y_i)}{\sum_{i=1}^{n} \mu_B(y_i)}, \tag{A.1}$$

where y_i is the center of the fuzzy set B (membership function μ_B).

AHP method

The concept of AHP was developed, among other theories, by Thomas Saaty, an American mathematician working at the University of Pittsburgh. It is an approach to decision making that involves structuring multiple choice criteria into a hierarchy, assessing the relative importance of these criteria, comparing alternatives for each criterion, and determining an overall ranking of the alternatives.

Matrix normalization

Normalized matrix of $A(x_{ij})$ is given by $A_{\text{norm}}(a_{ij})$

$$a_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}}}, \quad a_{ij} \in [0,1]. \tag{A.2}$$

NOMENCLATURE

ABC:	Always best connected
AHP:	Analytic hierarchy process
CoA:	Care of address
FGWN:	Future generation wireless networks
FL:	Fuzzy logic
HA/FA:	Home/foreign agent
HoD:	Handover decision
HoE:	Handover execution
HoIG:	Handover information gathering
HoPR:	Handover policies repository
MADM:	Multiple attribute decision making
MAHO:	Mobile-assisted handover
MCDM:	Multiple criteria decision making
MCHO:	Mobile-controlled handover
MIH:	Media independent handover
MIP:	Mobile IP
MODM:	Multiple objective decision making
MT:	Mobile teminal
NCHO:	Network-controlled handover

REFERENCES

[1] J. McNair and F. Zhu, “Vertical handoffs in fourth-generation multinetwork environments,” *IEEE Wireless Communications*, vol. 11, no. 3, pp. 8–15, 2004.

[2] E. Gustafsson and A. Jonsson, “Always best connected,” *IEEE Wireless Communications*, vol. 10, no. 1, pp. 49–55, 2003.

[3] H. Wang, R. Katz, and J. Giese, “Policy-enabled handoffs across heterogeneous wireless networks,” in *Proceedings of the 2nd IEEE Workshop on Mobile Computing Systems and Applications (WMCSA ’99)*, pp. 51–60, New Orleans, La, USA, February 1999.

[4] P. M. L. Chan, R. E. Sheriff, Y. F. Hu, P. Conforto, and C. Tocci, “Mobility management incorporating fuzzy logic for a heterogeneous IP environment,” *IEEE Communications Magazine*, vol. 39, no. 12, pp. 42–51, 2001.

[5] T. Ahmed, K. Kyamakya, and M. Ludwig, “A context-aware vertical handover decision algorithm for multimode mobile terminals and its performance,” in *Proceedings of IEEE/ACM Euro American Conference on Telematics and Information Systems (EATIS ’06)*, pp. 19–28, Santa Marta, Colombia, February 2006.

[6] I. 802.21, “Draft IEEE Standard for Local and Metropolitan Area Networks: Media Independant Handover Services, IEEE P802.21/D02.00,” September 2006, http://www.ieee802.org/21/.

[7] C. E. Perkins, “Mobile IP,” *IEEE Communications Magazine*, vol. 40, no. 5, pp. 66–82, 2002.

[8] 3GPP, “3GPP System to Wireless Local Area Network (WLAN) Interworking; System Description (Release 7), 3GPP TS 23.234 V7.5.0,” March 2007, http://www.3gpp.org/.

[9] F. Zhu and J. McNair, “Multiservice vertical handoff decision algorithms,” *EURASIP Journal on Wireless Communications and Networking*, vol. 2006, Article ID 25861, 13 pages, 2006.

[10] A. Hasswa, N. Nasser, and H. Hassanein, “Tramcar: a context-aware cross-layer architecture for next generation heterogeneous wireless networks,” in *Proceedings of IEEE International Conference on Communications (ICC ’06)*, vol. 1, pp. 240–245, Istanbul, Turkey, June 2006.

[11] S. Balasubramaniam and J. Indulska, “Vertical handover supporting pervasive computing in future wireless networks,” *Computer Communications*, vol. 27, no. 8, pp. 708–719, 2004.

[12] T. L. Saaty, “How to make a decision: the analytic hierarchy process,” *European Journal of Operational Research*, vol. 48, no. 1, pp. 9–26, 1990.

[13] P. Chan, Y. Hu, and R. Sheriff, “Implementation of fuzzy multiple objective decision making algorithm in a heterogeneous mobile environment,” in *Proceedings of IEEE Wireless Communications and Networking Conference (WCNC ’02)*, vol. 1, pp. 332–336, Orlando, Fla, USA, March 2002.

[14] M. Kassar, B. Kervella, and G. Pujolle, "An overview of vertical handover decisionstrategies in heterogeneous wireless networks," *Computer Communications*, vol. 31, no. 10, pp. 2607–2620, 2008.

[15] M. Kassar, B. Kervella, and G. Pujolle, "Architecture of an intelligent inter-system handover management scheme," in *Proceedings of the Future Generation Communication and Networking (FGCN '07)*, vol. 1, pp. 332–337, Jeju, Korea, December 2007.

[16] H.-H. Choi, O. Song, and D.-H. Cho, "Seamless handoff scheme based on pre-registration and pre-authentication for UMTS-WLAN interworking," *Wireless Personal Communications*, vol. 41, no. 3, pp. 345–364, 2007.

[17] R. A. Ribeiro, "Fuzzy multiple attribute decision making: a review and new preference elicitation techniques," *Fuzzy Sets and Systems*, vol. 78, no. 2, pp. 155–181, 1996.

[18] Q.-T. Nguyen-Vuong, N. Agoulmine, and Y. Ghamri-Doudane, "Terminal-controlled mobility management in heterogeneous wireless networks," *IEEE Communications Magazine*, vol. 45, no. 4, pp. 122–129, 2007.