Adaptive Decision Making Strategy for Handoff triggering and Network Selection

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Abstract— **Next generation mobile networks (4G) is expected to integrate a large number of wireless technologies. However, this integration yields many challenges such as those pertaining to handoff triggering and decision making. Various approaches have been proposed to solve these problems, yet handoff initiation and network destination selection remain critical issues which are widely based on RSS (Received Signal Strength) measurements. Moreover, the use of context-awareness is very limited in the previous works. This paper proposes a new handoff decision strategy which aims to efficiently deal with handoff triggering and network destination selection with respect to mobile terminal requirements and network capabilities. Furthermore, we introduce a new score function that estimates network preferences for both voluntary and forced handoffs. Additionally, to render easier the accessibility to context information, we develop a context aware mechanism which is based on third party architecture. Finally, simulation results show that compared to RSS-based approaches, the proposed handoff decision strategy has greater respect for users' requirements and preferences.**

Index Terms— **Handoff strategy, Decision making, Context-awareness, Handoff triggering.**

I. INTRODUCTION

Rapid progress in wireless network and communication technologies has created a wide variety of mobile systems. For example, Bluetooth is used in indoor areas, IEEE 802.11 in local areas, Universal Mobile Telecommunication System (UMTS) in expanded areas and satellite networks for global coverage. In order to take advantage of these complementary technologies, the next generation of mobile systems (4G) is expected to integrate a large number of these heterogeneous wireless systems [1]. According to emergent trends in mobile communication, 4G systems will guarantee seamless roaming and quicker handoffs through heterogeneous technologies. However, seamless mobility is more complex, as the integrated environments will support different wireless technologies.

Handoff management refers to the process of transferring a mobile user between cells of the same or a different network without disrupting connections [2]. Handoffs performed between cells that belong to the same network are considered *homogeneous* and the handover is called *horizontal*. This kind of handoff is mainly caused by the movement of the mobile user out of the coverage area of its current cell. On the other hand, handoffs performed between cells that belong to different networks are considered *heterogeneous* and this type of handoff is referred to as *inter-system* or *vertical handover* (VHO) [3].

Depending on the initiation reasons, handoffs can be either forced or voluntary. Handoffs caused by low link quality (weak RSS, low bandwidth, high traffic, etc.) are qualified as *forced,* since mobile nodes must select a new destination and execute the handoff process as quick as possible, while the voluntary handoff aims to maximize users' satisfaction [4]. Actually, handoff triggering remains an important task to be investigated for the next generation of mobile networks since the received signal strength (RSS) measurements are not enough to decide when to initiate handoffs [5]. Indeed, an MN may have a good RSS signal which is associated with very low bandwidth or high traffic conditions. It is obvious that, in such circumstances, the MN has to trigger a handoff especially if it carries on a multimedia traffic. Moreover, during handoff triggering an MN must decide whether to trigger a forced or a voluntary handoff since the former aims to avoid QoS deterioration while the latter is used to improve MN's preferences.

Once a handoff initiation takes place, the MN has to select its future network destination. This issue is known in the literature as handoff decision or network selection. It consists of selecting a network/AR that provides best QoS conditions with respect to MN's requirements and network capabilities [6]. The network selection (i.e., handoff decision) is generally initiated when the received signal strength (RSS) quality reaches a given threshold. However, in 4G, the RSS from different networks do not have the same meaning since each network is composed of its specific characteristics and there is no common pilot signal. Then, RSS comparisons are insufficient for handoff decision and may be inefficient or impractical. A more complete decision criterion that may combine a large number of parameters such as monetary cost, bandwidth, power consumption and user preferences is necessary.

Furthermore, handoff decision is typically based on a score function to complete network selection. Thus, the quality of the selected network destination depends on the way the score function is designed. We advocate that an efficient score function must consider forced and voluntary handoffs as well as network stability. The handoff type (i.e., forced and voluntary handoffs) can be used to choose adequate context parameters to perform handoff decision while network stability can be considered to eliminate networks that present rapid and high QoS variations. Finally, context awareness is also an important task to be addressed in order to specify how context information is provided for both handoff triggering and network selection.

Based on the aforementioned motivations, this paper proposes a new handoff decision strategy that deals with handoff triggering and network selection. More specifically, the main contributions of this paper consist in: (1) proposing a handoff triggering scheme based on fuzzy logic to decide which type of handoffs to initiate (forced vs voluntary) and under which conditions, (2) designing a handoff preference function that takes into account both forced and voluntary handoffs in order to perform best network selection, (3) proposing a context aware mechanism that ensures data sharing and provide various context information, (4) Analyzing the performances of the proposed handoff decision strategy.

The remainder of this paper is organized as follows: Section II introduces the related work. Section III describes the proposed context aware mechanism. Section IV outlines the proposed handoff decision strategy. Section V presents and discusses the obtained results and finally, Section VI concludes the paper.

II. Related work

In the traditional cellular systems, such as the global system for mobile communication (GSM), a threshold comparison of several specific metrics is used to make handover decisions. The most common metrics are Received Signal Strength (RSS), Signal-to-Interference Ratio (SIR) and Bit Error Rate (BER). However, RSS comparisons fail to consider network capabilities and mobile users' options [7]. Therefore, RSS measurements alone are insufficient for handoff decisions. To overcome this drawback, several handover decision strategies have been proposed in the literature. These proposals can be divided into: multi-criteria, Fuzzy Logic (FL) and Neural Network (NN) based, context-aware, user-centric and decision function based strategies [5].

First, the multi attribute decision strategies aim to deal with network destination selection among a limited number of candidate networks belonging to different technologies with respect to various criteria. This is known in the literature as multi attribute decision making problem (MADM) [8]. The popular MADM resolution methods are: SWA (Simple Additive Weighting), TOPSIS (Technique for Ordered Preference by Similarity to ideal Solution), AHP (Analytical Hierarchy Process) and GRA (Grey Relational Analysis). In this sense, a network selection mechanism that combines AHP and GRA has been proposed in [9] to find a tradeoff between user preferences, service application and network conditions. The results revealed that this selection approach can work efficiently for an UMTS/WLAN system. However, MADM based solutions remain insufficient to handle decision with imprecise criteria.

Second, to overcome the weakness of using imprecise parameters in the MADM strategies, Fuzzy Logic (FL) and Neural Networks (NN) concepts are then introduced for network selection. In this sense, an advanced neural-network-based vertical handoff algorithm was developed in [10] to satisfy users' bandwidth requirements. However, this type of solution does not specify how to get context information. Additionally, training of the neural network has to be done beforehand. In [11], the authors proposed a solution incorporating Fuzzy Logic in which terrestrial and satellite mobile networks operate alongside each other. In this case, handover decision aims to select a segment or a network for a particular service that can satisfy objectives based on criteria such as: low cost, good RSS, optimum bandwidth, low network latency, high reliability, long life battery and preferred access network. In [12], the FL and NN concepts are used together to provide handoff decision making. However, these solutions lack in using efficient context awareness since private networks and operators are very reticent to share their own context information.

Third, the context-aware based handover concept uses context information of both mobile node and networks to take decision whether a handoff is necessary on the access network target [13]. In [14], the authors present a framework with an analytical context categorization and a detailed handover decision algorithm. Prototype experiments have used different type access networks and streaming applications. It has shown that this approach can be used to deal with handoff selection. However, context information gathering needs frequent communications between the MN and the network, resulting in increased overhead on the radio link.

Fourth, user-centric strategies focus on user satisfaction in terms of monetary cost and QoS. More specifically, this type of solutions propose handoff decision policies and criteria to select the most appropriate network that answers user satisfaction and network efficiency. For example, a handover decision model designed from the user point of view is presented in [15]. The authors propose two handoff decision policies (fixing a threshold value) between GPRS and WIFI networks. One of these policies aims to satisfy the user who is willing to pay for having its connections as granted as possible, while the other one tries to satisfy the user from connection cost point of view but will disappoint his expectation of QoS. In [16], the authors give special focus to user satisfaction by using a utility function for non-real time applications such as FTP (file transfer). The network decision algorithm is based on the difference between the monetary value of data transferred and the real price charged with time completion prediction. The designed utility function uses decision metrics such as user's risk attitude (finding a compromise between paying less and accepting delays).

Fifth, handoff decision strategies that are based on cost functions focus on evaluating each one of the networks that are willing to support user services. Handoff decision algorithms, in this case, can be expressed as a sum of weighted functions of specific parameters. In [17], a policy-enabled handoff decision algorithm is proposed along with a cost function that considers several context parameters. However, this cost function is very simple and cannot handle more sophisticated scenarios. In [18], an adaptive multi-criteria handoff decision algorithm for radio heterogeneous networks was introduced. In [19], a method that considers both RSS and bandwidth as two important parameters for the cost function was developed, although this investigation only considers a single RSS threshold which could cause a ping-pong effect.

III. Proposed context aware mechanism

As stated earlier, context awareness is an important task to be addressed in order to provide context information while triggering handoffs or selecting new network destinations. In fact, without prior knowledge, a mobile terminal must scan channels of different frequencies to discover existing nearby networks. As reported in [13], scanning 13 channels in 802.11b WLAN requires in excess of 400 ms. Moreover, to the best of our knowledge, all of the previous work dealing with context-awareness assume that context information can be obtained and exchanged through heterogeneous networks. Practically, operators and private networks are very reticent to the idea of sharing their context information. An eventual possibility to get context information consists of using the Candidate Access Router Discovery protocol (CARD) [20] which aims to reduce latency, packet loss and avoid the re-initiation of signaling from the beginning during a handoff. However, acquiring context information with the CARD protocol requires L2 ID detection which is possible only when the associated air-interfaces are always on. Additionally, authentication is needed between entities exchanging context parameters which yield addition delays and render the authentication procedure very difficult to execute when the number of the MN's neighbors increases. Thus, we propose to use local context aware servers that provide context information relevant to their serving home network. In the rest of this section, we present the architecture, the logical modules and the context-aware procedure relevant to the proposed context-aware mechanism.

1. *Architecture*

Fig. 1, depicts the proposed context aware architecture that can be appropriate for Metropolitan networks. For simplicity, we consider here two networks connected to an IP backbone. Each network possesses a context-aware server (CAS) which manages local context information (i.e., context information relevant to each integrated network). Every CAS is identified by a *CAS_identifier* which is broadcasted through periodic router beacons. *Network 1* and *network 2* are respectively connected to an IP backbone via CAS1 and CAS2. We also introduce an interworking cooperation server (ICS) that ensures context information sharing between heterogeneous technologies. The ICS unit can be owned by an independent authority or operator. We also assume that both *network 1* and *networks 2* have a registration entry with the ICS. This means that their respective context aware servers (CAS1 and CAS2) can periodically and securely exchange context information with the ICS. Notice that the architecture bellow can be easily extended to more than two networks since the ICS manipulates only signaling traffic.

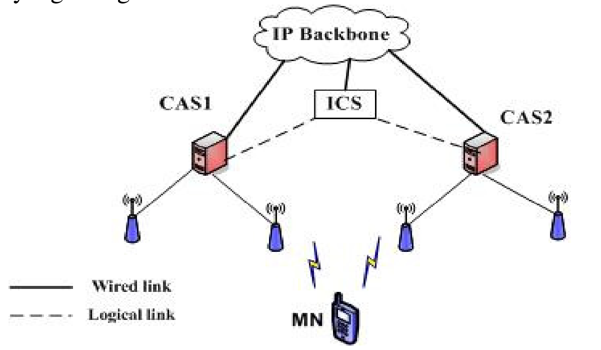

Fig. 1. Context-aware architecture

2. *Context-aware logical modules*

The logical modules relevant to the MN, CAS and ICS are illustrated in Fig. 2.

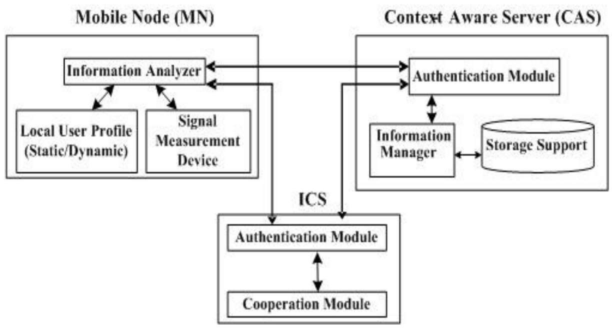

Fig. 2. Context-aware logical modules

The MN's logical modules

- *Information Analyzer (IA)*

The main role of this module consists of managing local context information (i.e., RSS, SNR, BER, etc.), performing handoff triggering and selecting new network destinations.

- *Signal Measurement Device (SMD)*

The SMD module performs RSS measurements and continuously updates the local user profile (LUP).

- *Local User Profile (LUP)*

The LUP unit operates as a local database that stores both static and dynamic context information relevant to the MN. The static information may concern wireless card type, public encryption keys, etc., and dynamic information may concern MN's velocity, mobility patterns, RSS measurements, moving history, etc.

The CAS's logical modules

- Authentication Module (AM)

The AM refers to the entity that communicates with external components and authenticates mobile users and CAS/ICS units.

- The Information Manager (IM)

The information manager (IM) manages local context information (inside a subnet or a network) and sends periodic context information to update CAS profile at the ICS. In this case, context information may refer to residual bandwidth, traffic status, connection blocking rate, etc.

- Storage Support (SS)

The role of this entity is to store local network context information. However, it can also manage basic operations such as deleting obsolete information and providing novel data structures for new ones.

The ICS's logical modules

- Cooperation Module (CM)

This unit manages MN's requests and cooperates with distributed CASs to get accurate context information. Additionally, the CM allows QoS mapping between various mobile technologies. Mapping is needed to translate the QoS guarantees and specifications provided for a session across heterogeneous systems. The QoS mapping performed by this unit refers, for instance, to the requirements relevant to resource reservation subjected to the pre-established service level agreements (SLAs) between networks.

3. Context-aware procedure

The context aware procedure refers to how context information can be obtained by using the context aware architecture depicted above. More specifically, context information may concern either the MN's home network or those relevant to its candidate destinations.

Locally, an MN may need context information such as RSS signal quality, residual bandwidth, traffic status, average residence time, etc, to evaluate an eventual handoff triggering. Practically, a number of context parameters relevant to the RSS quality can be computed by the MN itself. However, other ones like traffic status or average residence time are provided by the local context aware server. For instance, when an MN needs local context information, it sends a *context_req* message to its serving CAS. Upon receiving the MN's request, the CAS provides the requested parameters, when it is possible, and sends a *context_rep* reply to the MN.

On the other hand, when an MN wants to leave its home network toward one of its nearby destinations, it has first to perform a network selection. Nevertheless, operators are reticent to the idea of sharing their context information. Thus, to respect network's privacy, the MN sends a *select_req* message to the ICS through its serving context aware server (e.g. CAS_0). The ICS refers to the independent trusted authority. This message contains a list of needed context information to be provided as well as the identifiers of the MN's neighbor CASs to be contacted. The ICS authenticates the MN and sends a *context_infos_get* to the entire CASs located in the MN's vicinity. Each CAS replies to the ICS with a *context_infos_rep* that contains the requested context information. Finally, the ICS computes the pre-configured score function and sends a *select_rep* message that contains a list of candidate destinations to the MN. Fig. 3, shows the message flow in the presence of *n* CAS servers.

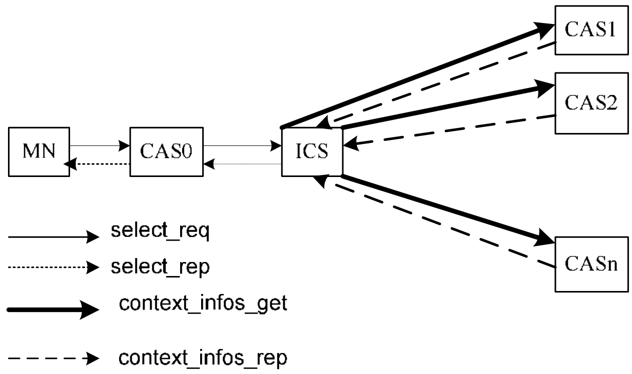

Fig. 3. Context-aware flow messages

In this way the MN reduces signaling traffic in the wireless link since it avoids requesting individually all of its neighbors for context information. Moreover, delays relevant to MN's authentication, with each CASs, are avoided because the requested context information is obtained through the ICS which is assumed to have secure entries with all the CASs. Finally, network privacy is guaranteed since the MN do not handle context information relevant to its nearby networks.

IV. Proposed context aware mechanism

According to the precedent literature review, it has been noticed that handoff initiation and network selection are still a challenging issue since RSS remains the most popular criterion used for these two tasks. In this section, we propose a new handoff decision strategy that considers more efficient context information while dealing with handoff initiation and network selection. More specifically, we first give an overview of the proposed strategy, and then we provide a detailed description of its main components. In the rest of this paper, mobile user and mobile node will be used interchangeably.

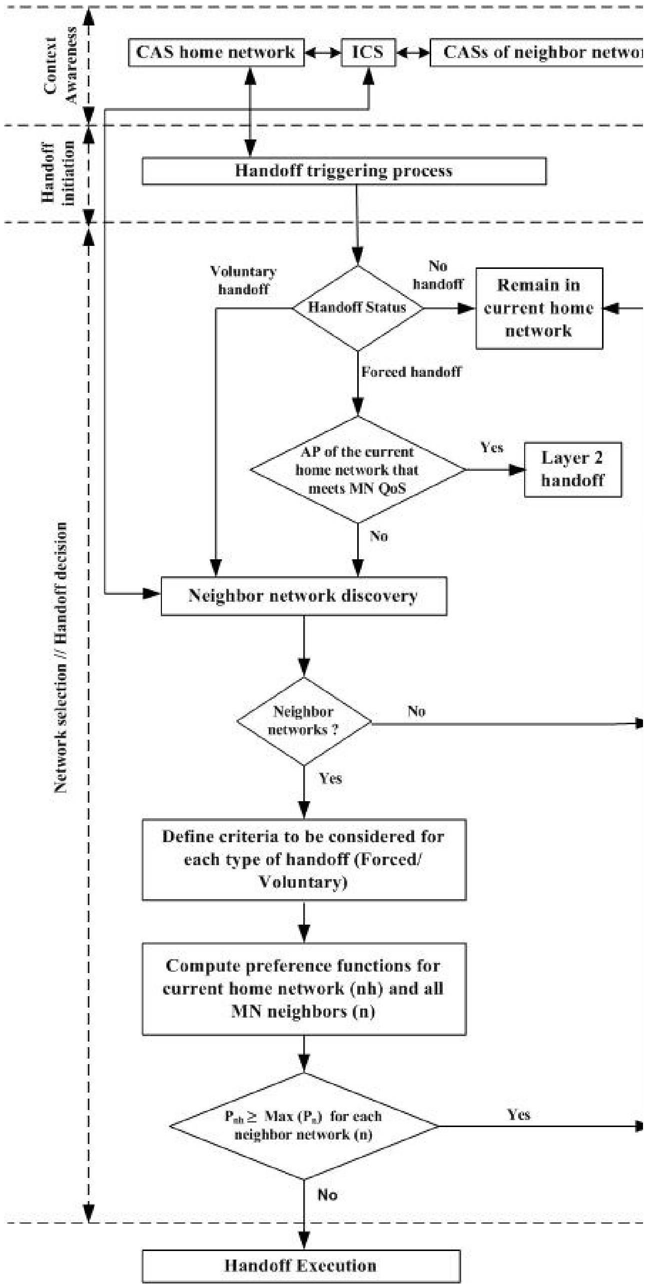

Fig. 4. Flow chart of the proposed handoff decision strategy (HDS)

1. Handoff decision strategy (HDS) overview

The proposed handoff decision strategy, referred to as HDS, is illustrated in Fig. 4. HDS combines context awareness, handoff initiation and network selection to provide adaptive handoff decision making.

When an MN receives a trigger event (TE), i.e., weak signal strength, poor bandwidth, high traffic status, etc., it performs the handoff triggering process depicted in Fig. 5. Then, it sends a *select_req* (new destination selection request) message to its serving context aware server (CAS). The *select_req* message includes information such as user preferences (weights) and thresholds (minimum QoS). Upon receiving the *select_req* message, the CAS verifies whether the MN can perform an L2 handoff. When this option is possible (e.g., performing an L2 handoff), CAS sends a *select_rep* reply that contains the prefix address of the selected NAR (new access router). Otherwise, the *select_req* message is sent to its serving ICS. Once this message is received, the ICS sends a *context_infos_get* message to the entire CASs located in the MN's vicinity. Then, each CAS replies with a *context_infos_rep* that contains the requested information. After that, the ICS computes a pre-configured preference score function and provides a list of candidate ARs (resp networks) that respects user requirements. Recall that this kind of pre-configured function can be defined during the system setup. Then it uses the *select_rep* message to send the list of candidate destinations that satisfy MN's requirements.

Once, the MN receives its *select_rep* message, it selects one AR/network destination and turns on its associated wireless interface. Then, it performs authentication and obtains a new IP address from the selected destination by using the IPv6 auto-configuration [21] or the DHCP [22] features. At this stage, the MN is ready to perform either horizontal or vertical handoff. In what follows, we give more descriptions relevant to the HDS modules.

2. HDS main modules

The main components of the proposed HDS are: context awareness, handoff initiation and network selection. We remember that the context awareness module has been already presented in section III, so its description will be skipped here. Thus, in the rest of this subsection, we focus on handoff triggering and network selection.

2.1 Handoff triggering

Handoff triggering is a crucial issue since the MN must decide which type of handoff to initiate and which context parameters to consider for that purpose. As stated before, the received signal strength is not enough to trigger efficient handoffs, i.e., on right time and under appropriate parameters. Thus, we advocate that handoff initiation should take into account various context criteria. However, it is impractical to use heterogeneous context criteria since these parameters can be expressed either in crisp or linguistic values. Moreover, it is difficult to find a tradeoff between the considered context parameters and the conditions to be meet to initiate handoffs. That is why we propose a fuzzy logic based solution that initiates handovers with different context parameter types (crisp, linguistic, etc.). In Fact, fuzzy logic [23] is a powerful concept that uses imprecise and uncertain data to produce precise values and actions. This is advantageous in the target networks because a fuzzy logic system is flexible and can be used to model nonlinear functions with arbitrary complexity.

As it is shown in Fig. 5, the first step of the proposed handoff initiation scheme consists in feeding the received context parameters into a fuzzifier. The main role of the fuzzifier is to transform real-time measurements into fuzzy sets, which contain elements with different membership degrees. For example, if the RSS signal is considered in a crisp set, it can be either weak or strong. However, in a fuzzy set, the RSS signal can be considered as quite weak, medium or strong. Membership values are generated by mapping the values obtained for particular parameters onto a membership function like the ones illustrated in Fig. 6. In general, these functions consist of a curve or line that defines how each datum or value is mapped onto a membership value. For instance, in Fig. 6a, S_1 is assigned the value 0.6 in the *Almost weak* set, 0.3 in the *weak* set and 0 in the *Medium* and *Strong* sets.

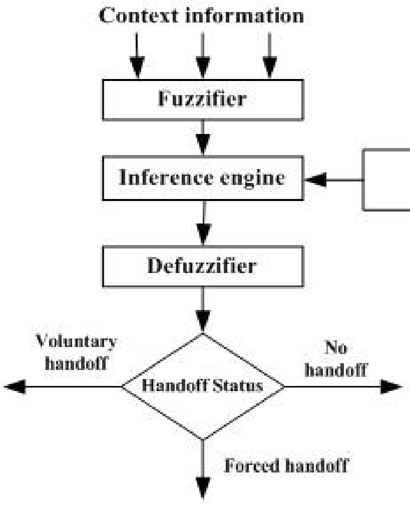

Fig. 5. Handoff triggering process

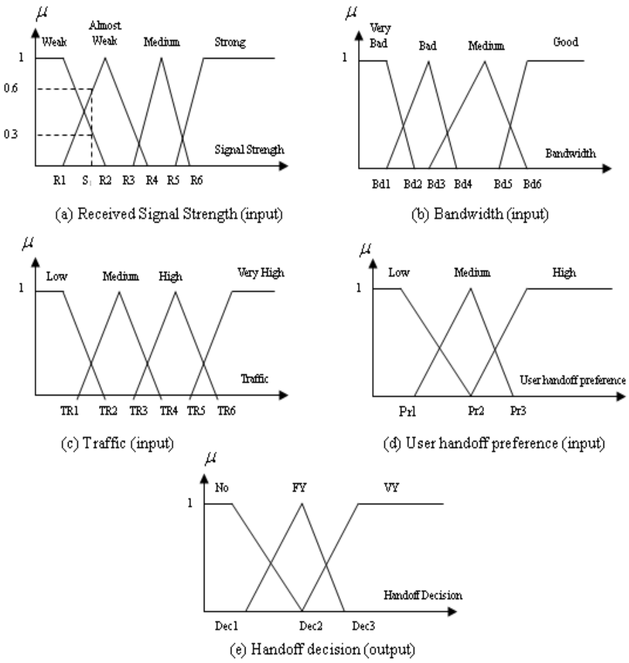

Fig. 6. Example of membership functions

The second step of handoff initiation involves feeding the fuzzy sets into an inference engine, where a set of fuzzy IF-THEN rules is applied to obtain fuzzy decision sets. Fuzzy rules can be defined as a set of possible scenarios which determine whether a handoff is necessary or not. The proposed initiation mechanism basically considers three decision sets: Forced Yes (FY), Voluntary Yes (VY) and No handoff (N). An example of IF-THEN fuzzy decision rules appears in Table 1. The output fuzzy decision sets are aggregated into a single fuzzy set and sent to the defuzzifier to be converted into a precise quantity during the last step of the handover initiation using the centroid method [24].

Table 1
Example of Fuzzy Rules

	Fuzzy Rules
Rule 1	IF (RSS is weak) or (Traffic is very high) or (Bandwidth is very bad) THEN Handoff is FY
Rule 2	IF (Bandwidth is bad) and (RSS is almost weak) THEN Handoff is FY
Rule 3	IF (Bandwidth is bad) and (Traffic is high) THEN Handoff is FY
Rule 4	IF (RSS is almost weak) and (Traffic is high) THEN Handoff is FY
Rule 5	IF (Bandwidth is medium) and (User handoff preference is high) THEN Handoff is VY
Rule 6	IF (Traffic is high) and (User handoff preference is high) THEN Handoff is VY
Rule 7	IF (RSS is medium) and (User handoff preference is high) THEN Handoff is VY
Rule 8	IF (RSS is almost weak) or (Bandwidth is bad) and (Traffic is high) and (Handoff preference is not Low) THEN Handoff is VY
Rule 9	IF (RSS is not almost weak) and (Bandwidth is not bad) and (Traffic is not high) and (Handoff preference is not high) THEN Handoff is N
Rule 10	IF (Handoff preference is low) THEN Handoff is N
Rule 11	IF (RSS is not weak) and (Bandwidth is not very bad) and (Traffic is not very high) and (Handoff preference is not high) THEN Handoff is N

2.2 Network selection

Network selection or handoff decision making refers to the process of choosing the most suitable network destination that satisfies MN's requirements in terms of QoS, monetary cost, security, battery consumption, user preferences, etc. Practically, this process passes though: neighbor network discovery, context preparation and score function calculation.

2.2.1 Neighbor network discovery

This phase consists in finding out all of the MN's neighbor networks which are willing to support its ongoing services. In fact, this task can be completed through the periodic beacons which include identifiers pertaining to MN's neighbor CASs. Otherwise, the MN sends a *neighbor_infos_req* message to the ICS which maintains a global view of the entire integrated mobile systems. The ICS replies with a *neighbor_infos_rep* message which contains a list of MN's neighbor networks.

2.2.2 Context preparation

Here, the MN defines its context criteria depending on the type of handoffs to be initiated (forced or voluntary). Moreover, it specifies context criteria thresholds, i.e., minimum QoS requirements as well as their corresponding weights. A number of these criteria are defined during the preliminary configuration of the MN/Network.

2.2.3 Preference function definition

The next generation of mobile networks (4G) aims to guarantee ongoing communications through heterogeneous mobile technologies. However, the selection of network destination that provides subscribers with better services remains a challenging issue and depends on several parameters such as : bandwidth, power consumption, user preferences, monetary cost, type of handoffs (forced vs voluntary), network stability, etc. The design of a handoff decision function that takes into account these parameters is crucial and needs a consensus between user requirements and network capabilities.

In this subsection, we propose a new handoff score function that allows a best network selection based on a wide range of context parameters including network stability. More specifically, it models the relationship between user services and network capabilities for both forced and voluntary handoffs. This means that the proposed handoff score function estimates network destination preferences depending on the type of the triggered handoff (forced or voluntary). In fact, forced handoffs need quicker network selection since mobile users have to complete immediately their handoff process. Therefore, the selected network destination is performed under minimum context parameters. In case of voluntary handoffs, network selection is performed with a large number of context variables. In what follows we present the proposed score function as well as its relevant computation procedure.

a) Preference function definition

Let C^F and C^V denotes respectively the sets of criteria used to select networks in case of forced and voluntary handoffs. Since forced handoffs are triggered with minimum context parameters, we assume that $C^F \subset C^V$.

In the rest of this section, mobile user and mobile node (MN) will be used interchangeably.

For a given mobile user *u*, we choose a network destination n^* that satisfies:

$$P_u^{n^*} = \underset{n \in N}{Max}\{P_u^n\} \qquad (1)$$

Where:

P_u^n refers to the estimated preference for network *n* to run on user services,

N denotes the set of neighbor networks.

P_u^n is defined by:

$$P_u^n = \begin{cases} P_{u,forced}^n & \text{if mobile user is subjected to a forced handoff} \\ P_{u,voluntary}^n & \text{if a mobile user is subjected to a voluntary handoff} \\ 0 & \text{Otherwise} \end{cases} \qquad (2)$$

$P_{u,forced}^n$ and $P_{u,voluntary}^n$ are respectively given by :

$$P_{u,forced}^n = (\sum_{i=1}^{m}\sum_{j=1}^{q} \omega_{s_i,c_j} \cdot P_{u,c_j}^{n,s_i}) \cdot R_{c,f}^n \ , \quad c_j \in C^F \qquad (3)$$

$$P_{u,voluntary}^n = (\sum_{i=1}^{l}\sum_{j=1}^{r} \omega_{s_i,c_j} \cdot (2 \cdot P_{u,c_j}^{n,s_i} - P_{u,c_j,precedent}^{n,s_i})) \cdot R_{c,v}^n \ , \quad c_j \in C^V \qquad (4)$$

Where:

ω_{s_i,c_j} denotes the weight to meet service s_i under criteria c_j, $\omega_{s_i c_j} \in [0,1]$, $\sum_{i,j} \omega_{s_i,c_j} = 1$,

P_{u,c_j}^{n,s_i} refers to the estimated preference to meet a user service s_i on network *n* under criteria c_j,

$P_{u,c_j,precedent}^{n,s_i}$: refers to the precedent estimated preference to meet a user service s_i on network *n* under criteria c_j,

$R_{c,f}^n$ and $R_{c,v}^n$ denote respectively factors relevant to forced and voluntary handoffs, which are used to eliminate networks that do not meet user's requirements. They are defined by :

$$R_{c,f}^n = \begin{cases} 1 & \text{if } \prod_{i,j} P_{u,c_j}^{n,s_i} \neq 0 \quad (i=1,.., m) \text{ and } (j=1,..,q) \\ 0 & \text{otherwise} \end{cases} \qquad (5)$$

$$R_{c,v}^n = \begin{cases} 1 & \text{if } \prod_{i,j} P_{u,c_j}^{n,s_i} \neq 0 \quad (i=1,.., l) \text{ and } (j=1,..,r) \\ 0 & \text{otherwise} \end{cases} \qquad (6)$$

Finally, to assess the stability of candidate networks and avoid the ping-pong effect, the term : $2 \cdot P_{u,c_j}^{n,s_i} - P_{u,c_j,precedent}^{n,s_i}$ (Equation (4)) is used to penalize instable networks and support the ones which improve QoS parameters. Indeed, the term $2 \cdot P_{u,c_j}^{n,s_i} - P_{u,c_j,precedent}^{n,s_i}$ is equivalent to $P_{u,c_j}^{n,s_i} + P_{u,c_j}^{n,s_i} - P_{u,c_j,precedent}^{n,s_i}$. Hence, if P_{u,c_j}^{n,s_i} is greater than or equals to $P_{u,c_j,precedent}^{n,s_i}$, the final score will be improved or remain stable (in case of equality), otherwise the final score will decease.

2.2.4 Preference function computation

The proposed preference function can be computed either at MN or at the ICS side. In fact, if we assume that mobile devices will become increasingly powerful, intelligent and sensitive to link layer changes we can adopt network assisted and mobile-controlled handoff strategy. This means that networks provide context information and the MN estimates their relevant preference functions to decide where to handoff. On the other hand, if MN capabilities are limited we will adopt mobile-assisted and network controlled strategy. In other words, the MN will provide it service's criteria in terms of QoS parameters, preference requirements (weights) and thresholds (i.e., minimum QoS), then the ICS computes the preference function pertaining to each candidate networks. We advocate that this last approach will allow the MN to save resources in terms of computing time and energy consumption. Moreover, the privacy of network's context information is respected since the MN will receive only results of score preferences relevant to each neighbor network rather than handling their context information.

2.3 Handover execution

The main concern of this module is to ensure service continuity while roaming through heterogeneous mobile systems. This task can be completed by Mobile IP [25] based solutions such as HMIP [26], FMIP [27], etc. It can also be completed at the transport layer by SCTP [28] based mobility schemes that use multihoming and dynamic address reconfiguration features.

V. SIMULATIONS AND RESULTS

In this section, we study the effectiveness of the proposed handoff decision strategy (HDS). To complete this task, we choose RSS based handoff decision strategy as a comparison benchmark since the RSS parameter is widely used in many previous work and systems [29][30]. More specifically, we first present the used simulation model, and then we discuss the obtained results.

1. *Experimental Model*

Fig. 7 depicts the simulation model used for performance analysis. Each BS_i refers to *network i* (i.e. *operator i*) which is supposed to use the same physical layer technology. We assume that BS_1 is enhanced with ICS features while the rest of BS_i (i = 2 to n) are endowed with CAS functionalities. In each experiment, the MN is assigned to *network 1* (i.e., BS_1) and moves in a constant speed from a start position (S) until the end position (E) located in the overlapping area as it is shown in Fig. 7.

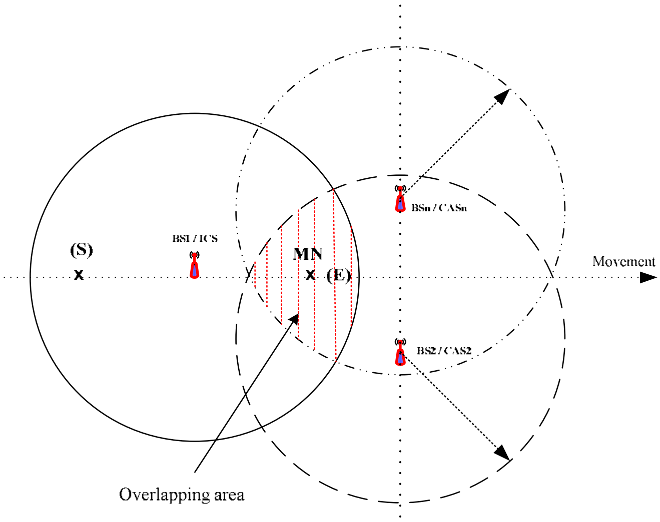

Fig. 7. Simulation model

All simulations are completed according to the process illustrated in Fig. 8. More specifically, this process starts by an initiation setup which consists of generating n overlapping networks as illustrated in Fig 7. When the MN reaches the overlapping area, we produce a random deterioration of the QoS parameters (i.e., RSS, bandwidth and traffic status) relevant to the MN's home network. Then, a Fuzzy Logic based triggering procedure is launched to decide whether to initiate a forced or a voluntary handoff. Depending on the type of the handoff to be triggered, each BS_i sends a list of context parameters to the ICS. Then, the ICS estimates a preconfigured preference function (depicted in section IV) for each *Network$_i$*. After, a list of Candidate Network destination is sent to the MN. Finally, the MN selects the destination having the maximum score result. The context parameters and their corresponding weights, considered in our experiments, are shown respectively in Table 2 and 3. The overall execution simulation process is outlined in Fig 8 and it is implemented in C++ and uses the Matlab Fuzzy tool.

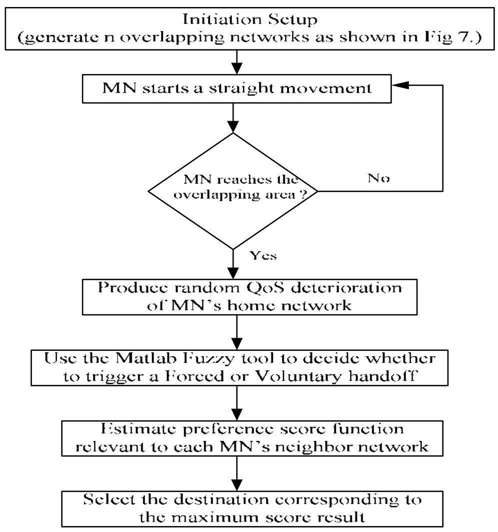

Fig. 8. Simulation execution process

The normalized preferences used for score calculations are defined by:

$P_{u,RSS}^{n,s_i} = \frac{RSS_n}{10}$, $RSS_n \in [0,10]$;

$P_{u,bandwidth}^{n,s_i} = 1 - e^{-B_n}$, B_n refers to the residual bandwidth on network n, $B_n \geq 0$;

$P_{u,price}^{n,s_i} = e^{-C_n}$, C_n refers to service cost per min, $C_n \geq 0$;

$P_{u,battery}^{n,s_i} = e^{-P_n}$, P_n equals to power consumption per hour,
$P_n \geq 0$;

$P_{u,sojourn}^{n,s_i} = 1 - e^{-S_n}$, S_n refers to sojourn time per MN visit,
$S_n \geq 0$.

$P_{u,traffic}^{n,s_i} = e^{-T_n}$, T_n indicates traffic status on network n,
$T_n \geq 0$.

The above context parameters can also be expressed in a quotient form i.e., $\frac{\left(X_n^{Max} - X_n\right)}{X_n^{Max}}$ (X_n refers to a context criterion n), however we will use the exponential form since it is easy to handle and avoids singularities while generating random values.

Table 2
Context criteria relevant to HDS and RSS-based handoff strategies

Type of handoff strategies				Context parameters
RSS-based	Handoff triggering		:	*RSS* of home network
	Network selection		:	*RSS* of neighbor networks
HDS	Handoff triggering		:	*RSS*, *Bandwidth* and *Traffic status* of MN's home network
	Network selection	Forced	:	*RSS*, *Bandwidth* and *Traffic status* of MN's neighbor networks
		Voluntary	:	*RSS*, *Bandwidth*, *Traffic status*, *Monetary cost*, *Power consumption*, *Sojourn time* of neighbor networks

Table 3
Example of service weights

Criterion	RSS	Traffic	Bandwidth	Price	Sojourn time	Battery
Normalized voice weights	0.225	0.125	0.175	0.2	0.15	0.125
Normalized download weights	0.162	0.109	0.216	0. 216	0.162	0.135

2. *Results*

This section presents and discusses results relevant to the use of the proposed HDS compared to the well-known RSS-based handoff strategy. More specifically, we investigate the impact of handoff initiation type (forced *vs* voluntary) on the quality of selected network destination.

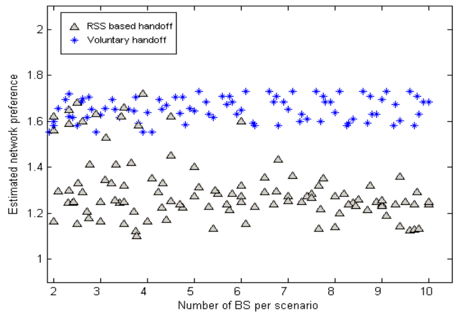

Fig. 9. Comparison of RSS vs. voluntary based handoffs

Fig. 9 illustrates the estimated preference score relevant to the selected network destination as a function of the number of MN's neighbor networks (BS_i). The first thing to be noted is that, the entire networks selected during voluntary handoffs are associated with high preference scores compared to the RSS-based handoffs. Such a situation is quite normal since during a voluntary handoff, the MN destination corresponds to the one that maximizes score preference under several context parameters. Therefore, the chosen destination meets all of the MN requirements, such as high bandwidth, maximal sojourn time, minimal financial costs, etc. On the other hand, the RSS-based handoffs select only networks that meet high RSS values. However, this type of selected network destination may have, for instance, poor bandwidth, low sojourn time, high monetary cost, etc. That is why the chosen networks under RSS comparisons show less score preferences compared to the ones selected in case of voluntary handoffs.

Fig. 10 illustrates score preferences relevant to the selected network destination when the MN is subjected to both RSS-based and forced handoffs. We notice that networks chosen when using forced handoffs show generally high preference scores compared to RSS-based handoffs. This is because when an MN performs a forced handoff, the proposed HDS allows it to consider at least 3 context parameters (e.g. RSS, bandwidth and traffic status) for network selection. Thus, the selected network destination satisfies MN's requirements in terms of RSS, bandwidth and traffic conditions. This is completely different from RSS-based strategy which tries to select a network destination that presents good RSS and remains unaware about the rest of MN's requirements.

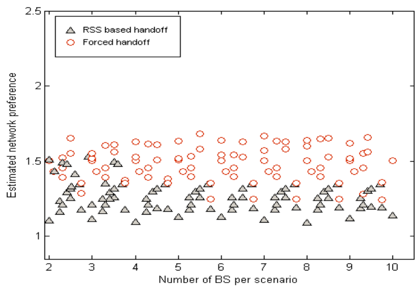

Fig. 10. Comparison of RSS vs. force-based handoffs

Fig. 11 shows results pertaining to the estimated preference score for both forced and voluntary handoffs.

Notice again that, voluntary handoffs allow the MN to select a high preference score networks. This means that the selected network destination, using a voluntary handoff, supports all of the user services and ensures better network parameters compared to force-based handoffs.

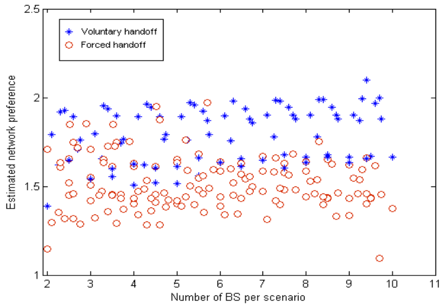

Fig. 11. Comparison of voluntary vs. force-based handoffs

To study the stability of the selected network destination when an MN is subjected to voluntary and RSS based handoffs. We define a stability factor as: $S_{fact} = e^{-\sum_{j} \frac{|c_j - c_{j,p}|}{c_j^{Max}}}$, where c_j refers to a context criterion j, $c_{j,p}$ indicates the previous value of criterion c_j and $c_{j,\max}$ corresponds to the maximum value of c_j.

Fig. 12 shows the behavior of the stability factor for both voluntary and RSS based handoffs. We notice that the stability factor relevant to the voluntary handoff presents low fluctuations and remains approximately equal to one. This means that the selected networks, when the MN performs a voluntary handoff, do not present noticeable variations in the considered context criteria (difference between current and old values). These results is due to the fact that the score function, used in case of voluntary handoffs, takes into account network stability as it is shown in Eq (4). However, in the case of RSS based handoffs, we notice more fluctuations in the stability factor. This means that the selected destination networks suffer from significant context variations which may lead to connection disruptions or performing handovers toward highly dynamic networks such as MANETs (Mobile Ad hoc NETworks).

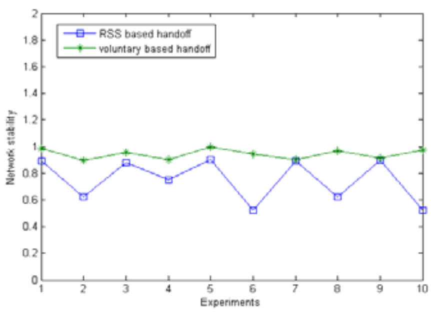

Fig. 12. Estimated network stability for voluntary and RSS based handoffs

Now, let n be the number of MN's candidate networks (i.e., number of MN's neighbor CASs). Fig. 13 illustrates the average exchanged wireless messages as a function of number of handoffs. We notice that the use of the ICS, during preference scores computation, leads to significant reduction of the wireless link load (in terms of wireless messages) compared to the case where the MN calculates its score function through the context aware servers (CAS-based). Indeed, when the MN uses the ICS, the wireless link is solicited two times per handoff (refer to the computation score procedure introduced in sub-section IV-2.2.4). However, without the ICS, the MN has to exchange wireless messages with each one of its neighbor CASs. Thus, the wireless link load increases depending on the number of MN's candidate networks (i.e. n).

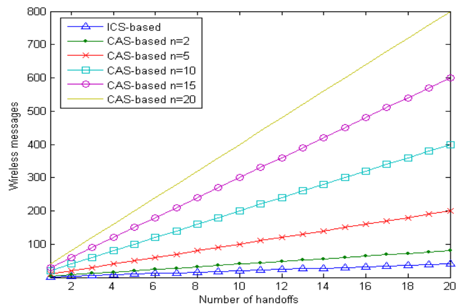

Fig. 13. Exchanged wireless messages

3. NS-2 Simulations

In this subsection, we study the effectiveness of the proposed strategy using NS-2 with NIST add-on [31]. In this case we endowed MN with the proposed HDS and RSS based decision modules. The considered scenario is presented in Fig 14. Mobile node (MN) is a multi-interface terminal. It is equipped with UMTS and WLAN interfaces. At the beginning, the only available network present is UMTS so the MN starts its connection via UMTS. The MN moves during the connection until it enters WLAN coverage. When it detects the presence of the WLAN network, it runs its decision module to decide whether to stay in the current home network or hands over to WLAN. The same experiment is repeated when the MN uses only the traditional RSS based strategy.

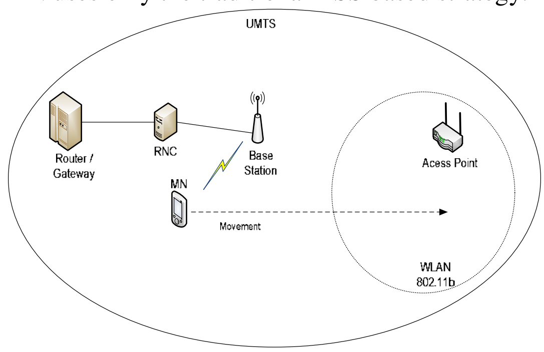

Fig. 14. Simulation network topology

In Fig. 15, we illustrate the residual bandwidth when the MN uses the proposed HDS and the RSS based strategies.

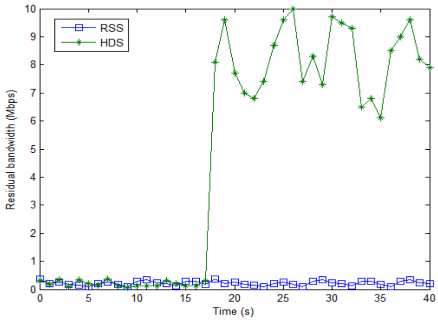

Fig. 15. Residual bandwidth

Before entering the overlapping area, we notice that the residual bandwidth is approximately constant. After t=17s, we observe that when the MN uses the HDS strategy, the residual bandwidth increases considerably while it remains almost unchangeable when the MN uses the RSS strategy. This situation is due to the fact that when the MN enters into the overlapping area, it detects the presence of the WLAN network. Hence, when using the HDS strategy, the MN performs a voluntary handoff to improve its available bandwidth. That is why we notice the increase of its residual bandwidth in this case. Nevertheless, with the RSS based strategy, the MN remains insensitive to the presence of WLAN since the quality of RSS signal remains acceptable.

VI. CONCLUSION

This paper proposes a new handoff strategy that uses fuzzy logic and context-awareness to improve the handoff triggering processes and arrive at a more efficient choice of MN network destinations. Unlike traditional decision approaches, this novel solution considers a large number of context information such as price, RSS, bandwidth, sojourn time, power consumption, etc. Such criteria are managed by an efficient context-awareness mechanism. Furthermore, a preference function was defined to model the relationship between MN requirements and network capabilities. This function models two types of handoffs, defined as forced and voluntary. Then, a fuzzy-based handoff triggering approach was proposed to select which kind of handoff (forced, voluntary) is to be initiated. The results thus obtained show that, voluntary handoffs ensure better network destination as compared to forced and RSS-based handoffs. This investigation also shows that forced handoffs yield better results, as compared to RSS-based handoffs, since they generally guarantee high network scores. In future work, we intend to compare the obtained results with other score methods such as TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) and AHP (Analytical Hierarchical Process). Additionally, we propose to model the user preference toward a handoff which refers to the real need to perform or not an eventual handoff. We expect that the introduction of such parameter will avoid unnecessary handoffs and then participates to optimize both MN and network resources.

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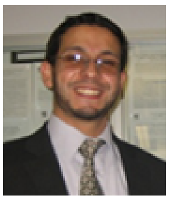

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