

A New Multi-Attribute Base-Station Association Technique for Hybrid Wireless Networks

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Abstract— **Handoff is the process of maintaining a user’s active session(s) when an MS changes its Point of Attachment (PoA) to a different wireless Network Access Technology (NAT). A horizontal handoff occurs between PoAs supporting the same wireless NAT, while for Vertical Handoffs (VHOs), the PoAs involve different NATs. A handoff decision includes the selection of a new PoA among all other available candidates based on certain criteria. Thus, efficient handoff schemes need to be designed to select a target network that can fulfill the QoS requirements for a wide variety of applications while allowing seamless mobility among a multitude of NATs. This paper presents a multi-criteria VHO algorithm for heterogeneous wireless networks, which achieves seamless mobility while maximizing end-users’ satisfaction. Two important modules are designed; the first module estimates the necessity of VHOs and the other module is developed to select the best network as the target of VHO. The target network selection algorithm is developed utilizing a weighting scheme that is based on the Analytic Hierarchy Process (AHP) and differentiates between different classes of traffic. Simulation results are provided and compared for four different traffic classes.**

Keywords-**Network Access Selection; Vertical Handoff; Heterogeneous Wireless Networks; WLAN; WMAN; WWAN; AHP; TOPSIS**

I. INTRODUCTION

Mobile Stations (MSs) in a typical 4G network are equipped with multiple interfaces to be able to properly choose among a variety of Network Access Technologies (NATs) using a procedure called Vertical Handoff (VHO). These NATs include different types of wireless technologies such as Code Division Multiple Access (CDMA), Global System for Mobile Communication (GSM), High Speed Downlink/Uplink Packet Access (HSDPA/ HSUPA), General Packet Radio Services (GPRS), Bluetooth-based Wireless Personal Area Network (WPAN), IEEE 802.11 Wireless Local Area Network (WLAN), IEEE 802.16 Worldwide Interoperability for Microwave Access (WiMAX), Vehicular Ad-hoc Network (VANET), and Satellite networks. The aforementioned technologies often have overlapping coverage in the same service areas and can offer innovative services based on user demands. The ultimate goal of such an environment is to provide simple, uninterrupted access to any type of desired services at any time, independent of devices, locations, and available networks [1], while maintaining satisfactory user experience in a cost-efficient manner. So far, significant research has been done to achieve seamless

mobility while an MS moves across different heterogeneous wireless networks. Many of the existing VHO algorithms are based on single metrics such as Received Signal Strength (RSS) and do not exploit the benefits of multi-criteria and the inherent knowledge about the sensitivities of these handoff parameters. Even the algorithms that consider several criteria, often miss important parameters related to Quality of Service (QoS) that plays an important role in end-users’ satisfaction during the VHO decision process. Another problem with the existing algorithms is that the assignment of preference weights for these parameters is done manually. Manual weight assignments do not consider how much of a weight is needed for a certain network parameter, which can lead to a degraded VHO performance. This becomes problematic especially during an ongoing session such as a Voice over IP (VoIP) conversations where achieving a minimum level of QoS is essential. Therefore, in order to guarantee the quality of the currently utilized service, proper weights assignment, especially for QoS-related parameters, is of utmost importance and should be done very carefully. Previous works mostly related to our research are reported in [2-4]. The authors in [2] utilize Analytic Hierarchy Process (AHP) for both weight elicitation and network selection processes. RSS is the only criterion that is used to trigger the handoff. This work is extended in [3] where authors implemented AHP weight elicitation process along with Techniques for Order Preference by Similarity to Ideal Solution (TOPSIS) to rank the networks. However, not all the QoS parameters are utilized to make selection decisions. The authors in [4] provide a scheme which utilizes AHP for VHO in a WiMAX/WLAN environment. Likewise, this work does not give any consideration to other important parameters such as RSS.

In this paper we propose a novel VHO algorithm for multi-traffic in a heterogeneous wireless environment. Our algorithm consists of two modules. The first one is the VHO necessity estimation (VHONE) module, which decides about the proper time to initiate the VHO. For this purpose, this module works with a wide range of system attributes with proper weight assignments, to form a VHO factor. AHP [5] is used to design the weighting system as the rating produced by AHP, coupled with other mechanisms, offers great flexibility (while sufficiently standardized) in allowing an MS to quickly and easily switch between different ratings for different applications. The second module is the NAT selection module which assigns the MS to the best available network. This

module is designed based on a well-known ranking method called TOPSIS. We assume four different types of traffic classes in this research and our NAT selection module is designed to adapt to the QoS requirements of each traffic class. Our scheme is examined by developing a comprehensive simulation test-bed which simulates a practical wireless environment with three different networks, i.e., WLAN, Wireless Metropolitan Area Network (WMAN) and Wireless Wide Area Network (WWAN). Necessary radio management modules are integrated into this test-bed, including user mobility and radio propagation modules. The performance of our scheme is evaluated by calculating the percentage of time that a moving MS is connected to each of aforementioned networks.

The remainder of this paper is organized as follows. Section II, explains our proposed scheme. Section III presents our simulation environment. Section IV discusses the simulation results and comparisons, using different network performance metrics. Finally, the work is concluded in section V.

II. PROPOSED SCHEME

Our proposed VHO algorithm consists of two modules; VHONE, which estimates the necessity of performing the VHO and the TOPSIS based NAT selection module. In the first stage of VHONE module, the attributes from all networks in range are measured and then weighted with respect to the traffic type. Our scheme utilizes a few carefully chosen attributes that are critical to maximize the end-users' satisfaction while performing VHOs. These attributes include network RSS, MS-velocity, distance between the Base Stations (BSs) and MS, network loading-conditions, security provided by the network, service-cost, and QoS parameters including network throughput, latency, jitter, and Packet Loss Ratio (PLR). In an attempt to improve the precision of the algorithm while reducing the outage probability of the VHO system, the future values for each network's RSS is predicted and used based on Grey Prediction Theory (GPT). Finally all these attributes are normalized and fed into the VHONE module to calculate a handoff factor, which is later compared against a certain threshold for making handoff decision. If the handoff factor goes above a threshold, the algorithm enters the NAT selection module, where the target network for handoff is determined. With the exception of distance between the MS and the serving Point of Attachment (PoA), the same attributes as in the VHONE module, are also utilized in the NAT selection module to determine the best target network. For more details on the design of VHONE module, readers may refer to [6]. In the following our weight calculation along with the NAT selection module are discussed.

A. AHP Weight Calculations for System Attributes

Making decisions while taking into account more than one criterion, is a common task and occurs all the time. Network selection problem exhibits the same characteristic and can be classified as an Multi Attribute Decision Making (MADM) problem where the goal is to find a network among

Table 1: AHP Fundamental Scale of Importance

Intensity of Importance	Definition
1	Equal Importance
3	Moderate Importance
5	Strong Importance
7	Very Strong Importance
9	Extreme Importance
2, 4, 6, 8	Intermediate Values

a set of candidates that can maximize end-users' satisfaction. Our scheme utilizes AHP to calculate weights for different system's attributes. The AHP method is introduced by Saaty [5] for solving complicated problems by dividing such problems into a hierarchy of easy to analyze decision factors and alternatives. AHP performs pairwise comparisons between the attributes and then transforms these comparisons scores into weights of decision criteria, and priorities of all alternatives on each criterion, to obtain the overall ranking of alternatives. It consists of the following steps:

1. *Determination of the objective and the decision factors*: In this step, the problem is divided into a hierarchal structure, which is comprised of the main objective, decision attributes, and the available alternatives. The decision attributes can be further decomposed into several sub-attributes, to any depth.

2. *Determination of the relative importance of the decision factors*: During this phase, pairwise comparisons between the attributes at each level of the hierarchy, is made. These comparisons are based on how strongly an attribute influences the other attribute in the pair, residing at the same hierarchy level. Table 1 depicts a fundamental scale, used for performing these comparisons. For example, while performing a pairwise comparison between two attributes "A1" and "A2", a value of "5" simply means that "A1" has a strong influence (5 times) over "A2". On the other hand a reasonable assumption can be made that "A2" will have a 1/5 influence over "A1". The comparison results are formulated in a square matrix according to $A = [a_{ij}]_{n \times n}$ where $a_{ii} = 1$, $a_{ji} = \frac{1}{a_{ij}}$, $a_{ij} \neq 0$ and n represents the number of decision attributes.

3. *Normalization and Calculation of the relative weights*: In this step, relative weights (w) are calculated by normalizing column vector if the matrix is consistent (rank = 1). In case of an inconsistent matrix, the largest Eigenvalue/Eigenvector method can be used. First the eigenvalues are calculated by solving $\det(\lambda I - A) = 0$, then the normalized weight vector can be obtained as follows:

$$Aw = \lambda_{max} w \quad (1)$$

where A is the AHP comparison matrix. A matrix with more than one eigenvalue indicates potential comparative inconsistency within the pairs of attributes. The Consistency Index (CI) and Consistency Ratio (CR) can be used to find these inconsistencies. They are defined as follows:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (2)$$

$$CR = \frac{CI}{RI} \quad (3)$$

where n is the number of elements being compared, and RI is the Random Consistency Index that is chosen based on the value of n . In practice, $CR \leq 0.1$ is considered acceptable; otherwise the subjective judgment of the decision makers related to the pairwise comparisons, needs to be revised.

One of the requirements of AHP is that it assumes independence between any two attributes residing at the same level of hierarchy. In the NAT selection problem, where the QoS parameters are also used as decision factors, there exists interdependence between delay, jitter, and PLR. This interdependence between these attributes must be resolved before finalizing the weights of these conflicting attributes. We resolve this interdependency by repeating the AHP process on the conflicting attributes pairs.

In order to maximize end-user's satisfaction, our scheme assigns higher weights to network RSS and QoS. Furthermore, since QoS requirements vary for various types of traffic classes, different weights with respect to these traffic types need to be calculated and assigned. The proposed scheme considers four different types of traffic classes (conversational, streaming, interactive, and background) with different characteristics and QoS demands as defined by 3GPP TS-23.107 [7] and shown in Table 2. Two hierarchy levels of criteria are considered. The order of preference for level-1 criteria, as utilized in our design is: RSS, QoS, MS-velocity, Network-Loading, Security, and Cost; where RSS and QoS are given equal importance as our goal is to maximize end-user satisfaction. Nonetheless, our scheme is flexible and the order of end-users' preferences may change based on their requirements. The relative importance for the first-level criteria is assigned by the end user whereas the relative importance for the second-level attributes, i.e., network throughput, latency, jitter and PLR, are defined by our proposed scheme. Readers may refer to [6] for details of our weight calculation technique for different traffic classes.

B. Target Network Selection

TOPSIS [8] is an MADM ranking algorithm, designed to measure the relative efficiency of the available alternatives based on certain criteria. One of the reasons for its popularity is that it requires limited subjective inputs from decision makers, which happens to be the preference weights assigned to different criteria. The principle behind this algorithm is very simple; the chosen alternative should be as close to the ideal solution as possible and as far from the negative-ideal solution as possible. The ideal solution is a composite of the best performance values, for each attributes, exhibited by any alternative. The negative-ideal solution is the composite of the worst performance values. The distance between each alternative and these performance values is measured in the Euclidean sense to calculate the relative closeness to the ideal solution. Note that this distance is affected by the decision maker's subjective preferences for each criterion. The steps for TOPSIS ranking procedure are given as follows:

Table 2: Traffic Classes with varying QoS requirements

Traffic Classes	Comments
Streaming	<ul style="list-style-type: none"> One-way transport Example: A user watching a video clip from YouTube or listening to his favorite radio channel over the Web End-to-end delay is not important Jitter and Throughput play an important role
Interactive	<ul style="list-style-type: none"> Two-way transport that relies on request/response mechanisms Example: User chatting with another user using Yahoo messenger or performing a financial transaction over the Web Delay and PLR are important Jitter and throughput are relatively less important
Conversational	<ul style="list-style-type: none"> Two-way transport Example: VoIP and video conferencing between end-users Delay and Jitter are critically important. PLR and throughput are relatively less important
Background	<ul style="list-style-type: none"> One-way transport Example: User sending SMSs or emails PLR is very important Delay, Jitter and Throughput are relatively less important

1. *Decision Matrix Construction*: A $m \times n$ decision matrix containing the ratings of each alternative with respect to each criterion is created as:

$$D = \begin{matrix} & C_1 & C_2 & \dots & C_n \\ \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} & \begin{bmatrix} d_{11} & d_{12} & \dots & d_{1n} \\ d_{21} & d_{22} & \dots & d_{2n} \\ \vdots & \vdots & \dots & \vdots \\ d_{m1} & d_{m2} & \dots & d_{mn} \end{bmatrix} \end{matrix} \quad (4)$$

where A_m is the m^{th} alternative and C_n is the n^{th} criterion. Each element d_{ij} of the decision matrix represents the performance rating of the alternative A_i with respect to the criterion C_j .

2. *Decision Matrix Normalization*: Decision matrix is normalized based on the following equation:

$$r_{ij} = \frac{d_{ij}}{\sqrt{\sum_{i=1}^m d_{ij}^2}} \quad i = 1, 2, \dots, m \quad j = 1, 2, \dots, n \quad (5)$$

where r_{ij} is the normalized value of the element d_{ij} .

3. *Weighted Normalized Decision Matrix Construction*: This matrix is constructed by multiplying each element r_{ij} with its associated weight w_j , as follows:

$$v_{ij} = r_{ij} \times w_j \quad (6)$$

4. *Calculation of Positive & Negative Ideal Solution*: The positive and negative ideal solutions, A^+ and A^- , respectively, are defined as:

$$A^+ = (v_1^+, v_2^+, \dots, v_n^+) = \{(\max_i v_{ij} | j \in C_B), (\min_i v_{ij} | j \in C_C)\} \quad (7)$$

$$A^- = (v_1^-, v_2^-, \dots, v_n^-) = \{(\min_i v_{ij} | j \in C_B), (\max_i v_{ij} | j \in C_C)\} \quad (8)$$

where C_B and C_C denote the sets with benefit and cost criteria, respectively.

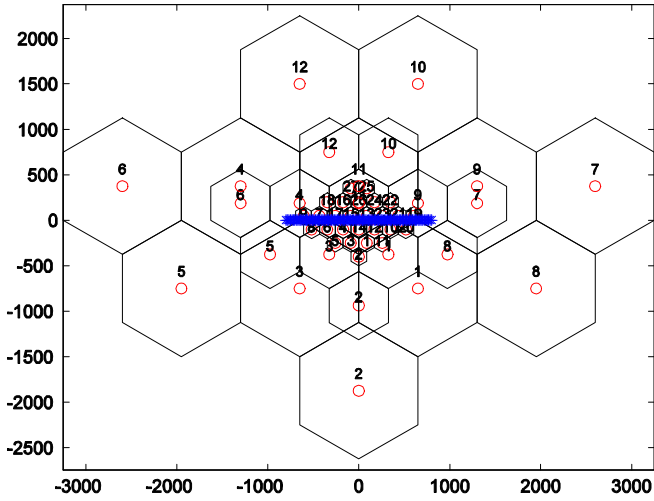


Figure 1: Network Topology

5. *Calculation of Separation between Alternatives & Ideal Solutions*: The separation (distance) between each alternative from the positive ideal (S_i^+) and negative ideal solutions (S_i^-) is calculated as follows:

$$S_i^+ = \sqrt{(v_{ij} - v_i^+)^2} \quad i = 1, 2, \dots, m \quad j = 1, 2, \dots, n \quad (9)$$

$$S_i^- = \sqrt{(v_{ij} - v_i^-)^2} \quad i = 1, 2, \dots, m \quad j = 1, 2, \dots, n \quad (10)$$

6. *Calculation of Relative Closeness to the Ideal Solution*: This step involves calculating the relative closeness (C_i) to the ideal solution, which is defined as:

$$C_i = \frac{S_i^-}{S_i^- + S_i^+} \quad i = 1, 2, \dots, m \quad (11)$$

7. *Ranking of the Alternatives*: The ranking of the alternative is performed by sorting the values of relative closeness C_i , in descending order. The best alternative has the highest value of C_i .

As part of the target network selection scheme, MATLAB code is implemented to perform the selection of the best network among the other available candidates, using a modified version of the above mentioned TOPSIS algorithm.

III. SIMULATION ENVIRONMENT

The VHONE and TOPSIS based NAT selection modules are implemented in MATLAB and evaluated using a comprehensive test-bed, developed based on the concept of Rudimentary Network Emulator (RUNE) [9]. RUNE is a special purpose simulator to simulate wireless networks. Three types of co-existing networks, i.e., WLANs, WMANs, and WWANs, based on a cellular concept are considered. The WLAN is defined with 27 cells with a radius of 100 meters each. The WMAN and WWAN are defined with 12 cells, each with a radius of 375 and 750 meters, respectively. The standard hexagonal shape with omni-directional antennas is considered for all cells. For the propagation model, we consider the path loss, shadow fading and Rayleigh fading. For performance evaluation, we consider a single user scenario, where an MS with variable speed, travels in a straight line and passes through the coverage of several cells

Table 3: Simulation Parameters

Parameters	WLAN	WMAN	WWAN
Cell Shape	Hexagonal with Omni-directional Antennas		
Mean Velocity (m/s)	0-10		
Thermal Noise Floor (dBm)	-118		
Standard fading deviation (db)	6		
Fading Correlation (downlink)	0.5		
Fading Correlation distance (m)	20		
Average Calls per Cell	1-10		
Min. RSS to connect (dBm)	-110	-160	-150
Attenuation at 1 m distance (db)	-40	-55	-28
Delay (ms)	130	30	10
Jitter (ms)	30	10	1
PLR (per 10^6 bytes)	5	4	2
Throughput (Mbps)	140	50	0.2
Security (1-10)	5	5	5
Cost (1-10)	2	4	7

located within the three networks. The network topology and the travelling path of the MS are shown in Figure 1. The networks' and simulation parameters are illustrated in Table 3.

IV. PERFORMANCE EVALUATION

Figures 2-5 show the percentages of MS-preferred connections to different types of wireless networks for conversational, interactive, background, and streaming traffic classes, respectively. Based on the network parameters provided in Table 3, the proposed scheme for the conversational traffic class prefers to connect to WLAN, approximately 98% of the time, for the slower moving MS. As depicted in Figure 2, at medium speed, WMAN can be seen as the preferred network with approximately 61% connections. Similarly, for a higher speed MS, the preferred connectivity by the MS is towards WWAN. It can be also noted from Figure 2 that WLAN shows a strong presence at medium and high speeds with higher preference towards WLAN as compared to other networks between MS-speed of 6-7 m/s.

A similar pattern like conversational traffic class can be observed for Interactive traffic class from Figure 3. At an MS speed of 7 m/s, a high connectivity MS-preference of approximately 90% can be seen towards WLAN.

For Background traffic class, WLAN seems to be the preferred network for both slow and fast moving MS. It can be observed from Figure 4 that an MS moving at slower or higher speed, WLAN connectivity preference is approximately 90%-95%. At medium speed, WMAN is the preferred network for the background traffic class.

A similar behavior like the background traffic class can be observed for Streaming traffic class, as shown in Figure 5. WLAN is a preferred network for slower and fast moving MS, while WMAN is selected by the MS with medium speed.

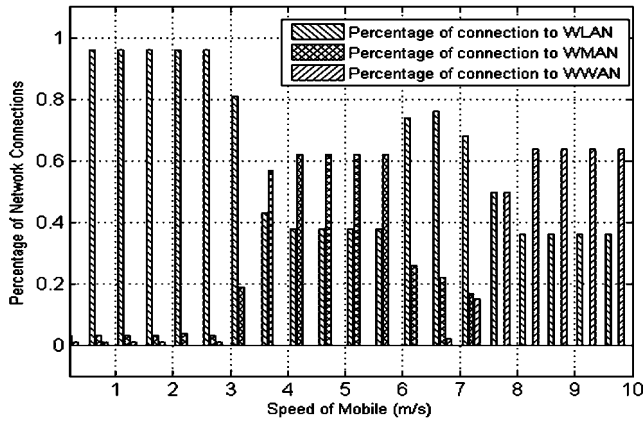


Figure 2: Percentage of NW-Connection for Topsis-AHP per different MS speeds, Conversational Traffic.

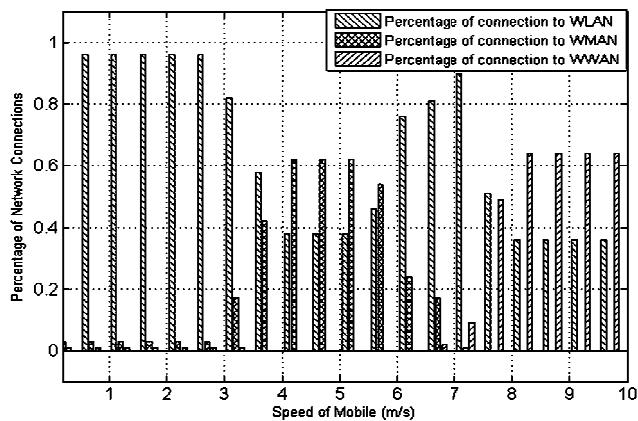


Figure 3: Percentage of NW-Connection for Topsis-AHP per different MS speeds, Interactive Traffic.

V. CONCLUSIONS

A Vertical Handoff (VHO) algorithm with two modules, namely, VHO Handoff Necessity Estimation (VHONE), and Target Network Selection, were proposed. The VHONE module determines whether a handoff is necessary by taking into consideration the predicted RSS values provided by the current point of attachment (PoA), the degree of the provided QoS based on the requested traffic class, and the speed of the MS including its direction. Later, these values are weighted based on a weighting scheme developed by the AHP process. The NAT selection module is designed using Topsis ranking algorithm and a novel weight elicitation technique that are implemented to select the best target network. It was observed that our VHO scheme assigns proper network to the moving MS based on the QoS requirements of the currently utilized class of traffic. For instance, for conversational class and for slower moving MS, our scheme prefers WLAN at 98% of the time, whereas for MS with medium and high speeds, our proposed scheme chooses WMAN and WWAN at 61%, and 63%, respectively.

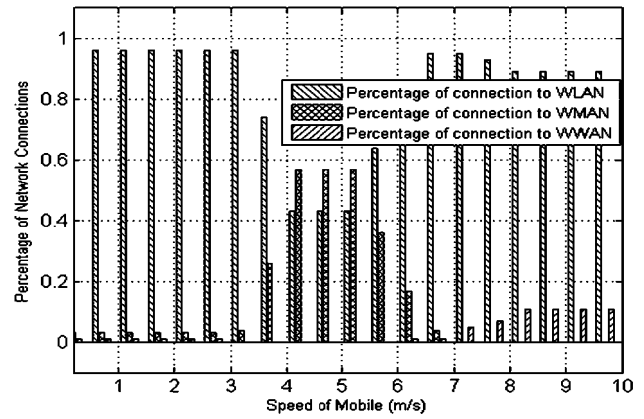


Figure 4: Percentage of NW-Connection for Topsis-AHP per different MS speeds, Background Traffic.

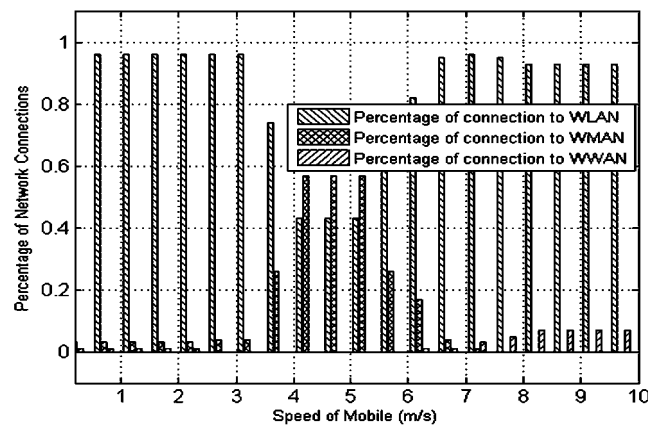


Figure 5: Percentage of NW-Connection for Topsis-AHP per different MS speeds, Streaming Traffic.

REFERENCES

- [1] G. Lampropoulos, A. K. Salkintzis and N. Passas, "Media-independent handover for seamless service provision in heterogeneous networks," *IEEE Communications Magazine*, vol. 46, pp. 64-71, 2008.
- [2] S. Dhar, A. Ray and R. Bera, "Design and Simulation of Vertical Handover Algorithm for Vehicular Communication," *International Journal of Engineering Science and Technology*, vol. 2, pp. 5509-5525, 2010.
- [3] S. Dhar, A. Ray and R. Bera, "A Context Aware Vertical Handoff Algorithm for Vehicular Communication," *International Journal of Electronics, Computer and Communications Technologies*, vol. 2, pp. 24-34, 2011.
- [4] A. Sgora, D. D. Vergados and P. Chatzimisios, "An access network selection algorithm for heterogeneous wireless environments," in *Computers and Communications (ISCC), 2010 IEEE Symposium on*, 2010, pp. 890-892.
- [5] T. L. Saaty and L. G. Vargas, *Models, Methods, Concepts & Applications of the Analytic Hierarchy Process*. Boston: Kluwer Academic Publishers, 2001.
- [6] F. Kaleem, "VHITS: Vertical Handoff Initiation and Target Selection in a Heterogeneous Wireless Network", PhD Dissertation, *Florida International University*, 2012, <http://digitalcommons.fiu.edu/etd/602>
- [7] J. Rinne, "3GPP Specification Details", TS 23.107.
- [8] T. Gwo-Hsiung and H. Jih-Jeng, "Multiple Attribute Decision Making: Methods and Applications", Chapman and Hall/CRC, 2011.
- [9] J. Zander and S. Kim, "Radio Resource Management in Wireless Networks", Artech House, 2001.