Multi-criteria Vertical Handoff Decision Algorithm Using Hierarchy Modeling and Additive Weighting in an Integrated WLAN/WiMAX/UMTS Environment– A Case Study

Sahana Bhosale[1], Rohin Daruwala[2]
[1]Department of Electronics and Telecommunication, Bharati Vidyapeeth's College of Engineering for Women, Pune – India
[e-mail: sahana.bhosale@bharatividyapeeth.edu]

[2]Department of Electronics Engineering, Veermata Jijabai Technological Institute (VJTI), Mumbai – India
[e-mail: rddaruwala@vjti.org.in]
*Corresponding author: Sahana Bhosale

Received May 3, 2013; revised August 25, 2013; revised November 18, 2013; accepted December 21, 2013; published January 29, 2014

Abstract

Multi-criteria decision making (MCDM) algorithms play an important role in ensuring quality of service in an integrated HetNets (Heterogeneous Networks). The primary objective of this paper is to develop a multi-criteria vertical handoff decision algorithm (VHDA) for best access network selection in an integrated Wireless Local Area Network (WLAN)/ Universal Mobile Telecommunications System (UMTS)/ Worldwide Interoperability for Microwave Access (WiMAX) system. The proposed design consists of two parts, the first part is the evaluation of an Analytic Hierarchy Process (AHP) to decide the relative weights of handoff decision criteria and the second part computes the final score of the weights to rank network alternatives using Simple Additive Weighting (SAW). SAW ranks the network alternatives in a faster and simpler manner than AHP. The AHP-SAW mathematical model has been designed, evaluated and simulated for streaming video type of traffic. For other traffic type, such as conversational, background and interactive, only simulation results have been discussed and presented in brief. Simulation results reveal that the hierarchical modelling and computing provides optimum solution for access network selection in an integrated environment as obtained results prove to be an acceptable solution to what could be expected in real life scenarios.

Keywords: HetNets, vertical handoff, decision criteria, MCDM, AHP, simple additive weighting, always best connected, streaming, conversational, interactive and background.

http://dx.doi.org/10.3837/tiis.2014.01.003

1. Introduction

HetNets demands integration and interoperability of existing wired and wireless access technologies and have introduced a concept called as Always Best Connected (ABC), which means not only being always connected, but also in the best possible manner [1,2]. The ABC concept of HetNets, for instance, integrates the worldwide coverage of low data rate cellular systems with high data rate service of WLAN within hotspots through seamless and efficient Vertical Handoffs (VHOs). Change of the Mobile Node's (MN) point of attachment (PoA) during active communication is called the handoff [3]. Traditionally, handoff is an intra-system handoff which is executed between two homogeneous access networks like between neighboring Base Stations (BSs) of WiMAX and is called as horizontal handoff (HHO). In contrast, VHO is an inter-system handoff which takes place between different heterogeneous network technologies such as WLAN, WiMAX, Cellular, Bluetooth etc [1].

Seamless and efficient handoffs indicate satisfactory Quality of Service (QoS) experienced by the user. But two aspects need to be analyzed while dealing with QoS requirements during the process of VHOs. One is the QoS experienced by a MN which is undergoing the process of handoff and other aspect is the integration of QoS parameters in the design of Vertical Handoff Decision Algorithm (VHDA) [5]. None of the VHDA discussed in the literature can support and guarantee both aspects of QoS for efficient handoffs but most of them try to minimize latency, packet loss, handoff failures and unnecessary handoffs while maximizing throughput [6,7,11,12].

Access network selection algorithms play an important role in ensuring QoS in heterogeneous networks. In this paper we develop such an algorithm for an integrated UMTS/WLAN/WiMAX system. ABC demand of HetNets requires comparing and judging various network related and MN related parameters. In this work, access network selection among WLAN, UMTS and WiMAX is done by using AHP of Multi-criteria decision making (MCDM) algorithms in two steps. First step analyzes and decides relative weights of the MN and network related criteria using AHP. Second step prioritizes and ranks the performances of access network alternatives using SAW as its implementation is faster and simpler than AHP. The reason for using a decision tool is the large amount of data that has to be compared and judged. Normally, the criteria are not easy to quantify and the most critical task in the decision process is to define those criteria that are of importance and relevance for a corresponding traffic type and application running on the MN. In this paper, simulations are conducted with the goal of best access network selection for streaming video traffic transmission by considering seven decision criteria such as speed of MN, bandwidth of the access network, Network Traffic Load (NTL), jitter, Bit Error Rate (BER), delay and Cost of usage of the network with three decision alternatives (WLAN, UMTS, WiMAX).

Simulations conducted in a heterogeneous system with UMTS, WLAN and WiMAX reveal that the proposed network selection technique can effectively decide the optimum network through making trade-offs among network condition, user preference, and application traffic type, while avoiding frequent handoffs.

The rest of this paper is organized as follows. Section 2 presents a review of past work. Section 3 provides MCDM concept and various design steps of AHP. Section 4 discusses the proposed hierarchical AHP design for the best access network selection amongst WiMAX, WLAN and UMTS. Section 5 provides performance analysis of access network selection with reference to the simulation scenario for streaming, conversational, interactive and background type of traffic. Finally, Section 6 provides concluding remarks.

2. Related Work

Variety of VHDAs [8,9,10] which are discussed in the literature have been designed by considering specific research goals and hence decision criteria (single, double, triple, or multi) adopted by these algorithms are quite heterogeneous in nature and so are their performance evaluation schemes. Most of the conventional handoffs (horizontal handoffs) are based on RSS but VHOs, in addition to RSS, are based on network related parameters like end-to-end delay, throughput, signal to interference and noise ratio (SINR), bandwidth, cost etc or MN related parameters like speed, location, trajectory, movement, battery power etc. Handoff decision takes into consideration one or more parameters depending on whether algorithm is single/double/triple or multi-criteria [9]. VHDAs are evaluated by generating some experimental or simulation topology which includes heterogeneous access technologies and handoff performance metrics are evaluated for different traffic classes (IMT-2000 QoS classes). Conversational, Streaming, Interactive and Background type of traffic classes are considered for experimentation and simulation purpose [11,12,13]. Conversational, streaming and interactive traffic classes expect less delay. Applications like conversational, interactive video conferencing and live streaming require more network availability, less end-to-end delay with tolerable bandwidth [13].

VHO decision algorithms are designed to select best access network and hence the design of such algorithms demand processing of diverse metrics and parameters. Consequently, a Multiple Criteria Decision-Making (MCDM) algorithm fulfils the need by taking into account all these diversified and processed parameters. Large number of research papers [14,15,16,17] have also discussed MCDM methods for the selection of best access network for variety of access technologies and traffic types. MCDM methods are actually implemented through any of the decision tools such as AHP. Variety of research proposals have addressed the final score calculation of AHP through SAW (Simple Additive Weighting), TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), GRA (Grey Relational Analysis) or MEW (Multiplicative Exponent Weighting) [8,18,19]. AHP using five decision criteria for vehicular communication has been designed and evaluated in [22,23,24].

Fuzzy Logic (FL) and Neural Networks (NN) concepts are combined with multiple attribute or criteria concept to design advanced decision algorithms. Classical MCDM methods require precise input data in order to weight attributes and to perform an accurate decision but many times collected input data and information is imprecise. In such cases, FL and NN techniques are applied to convert imprecise data into precise one and then these data is fed in a MCDM algorithm to determine the ABC network [29,31].

Fuzzy logic methods combined with MCDM algorithms are found in [27,28,29]. Similarly, Grey Relational Analysis (GRA) techniques are combined with fuzzy processes in [30]. A combination of fuzzy logic and a cost function-based for ABC network selection is discussed in [32].

Fuzzy logic and neural network based combination algorithms are more complex to implement as they process wider range of decision criteria and network parameters. Also, large number of research proposals found in the literature, address theoretical analysis stage of these combination algorithms. Hence, a fast MCDM algorithm combined with AHP and SAW to weigh the parameters and provide a quick VHO decision for selection of ABC network is recommended.

To the best of our knowledge, no previous works have actually designed and validated the MCDM-AHP-SAW steps to demonstrate access network selection in a HetNets scenario for steaming video, conversational, background and interactive traffic using seven distinct decision parameters. Experimentation and simulation of VHOs for streaming, background, interactive and conversational traffic types for HetNets infrastructures which integrates maximum number of existing wired and wireless access technologies is still a widely open issue. The work has its significance due to its timeliness as currently researchers look forward to some reliable platform and techniques for experimenting and simulating futuristic wireless communication systems, such as HetNets and beyond HetNets wireless.

3. Multi-Criteria Decision Making Using AHP

Multi-Criteria Decision Making (MCDM) consists of constructing a global preference relation for a set of alternatives evaluated using several criteria and selection of the best actions from a set of alternatives, each of which is evaluated against multiple and often conflicting criteria [19]. MCDM problem has four elements; Goal, Objectives, Criteria and Alternatives. The Analytic Hierarchy Process (AHP) [20] is a technique used for dealing with problems which involve the consideration of multiple criteria simultaneously. It is unique in its ability to deal with intangible attributes and to monitor the consistency with which a decision maker makes his decisions. AHP is defined as a procedure to divide a complex problem into a number of deciding factors and integrate the relative dominances of the factors with the solution alternatives to find the optimal one.

Our metric values are the input to the Multi-Criteria Decision Making (MCDM) process in which the transformed 9-point scale is being used. The outcome from the decision process is a weighted priority list which is fed into the roaming strategy box with the final goal of being ABC, see **Fig. 1**.

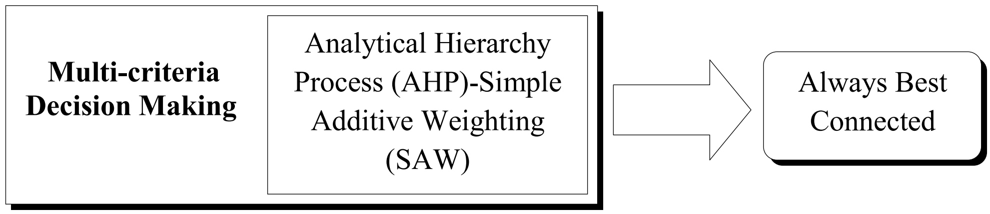

Fig. 1. MCDM – AHP - SAW

The AHP is carried out in five steps [20,21]

Step 1: To Develop Hierarchical Structure

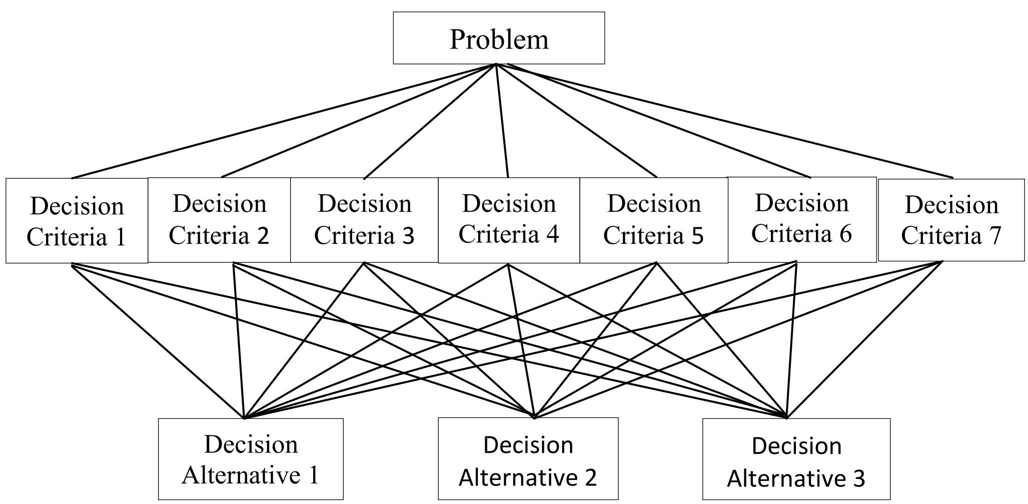

Fig. 2. AHP Decision Hierarchy [20]

Develop a hierarchical structure by decomposing the decision problem into several decision elements that are comparable to each other [22]. Fundamental structure contains ultimate goal at the top level, criteria in the middle level and alternatives at the bottom as shown in **Fig. 2**.

Step 2: To create pair-wise comparison matrix of decision elements.

AHP does pair-wise judgements by relating the importance of criteria i to criteria j with reference to ultimate goal set up in step 1. The fundamental scale of AHP is used to represent the relativity between decisions elements. The scale consists of nine levels. Judgements can be made easier by using restricted scale of lesser levels. Matrix A is created by pairwise comparisons, indicating the importance of criterion i to criterion j as shown in eq. 1

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & \cdots & a_{2n} \\ : & : & : & : & : & : \\ : & : & : & : & : & : \end{bmatrix} \quad (1)$$

Where $a_{ij} = 1$ for $i = j$ and $a_{ij} = 1/a_{ji}$ for $a_{ij} \neq 0$

Step 3: To estimate the relative weights of the Criteria

Relative weights of the criteria can be determined by normalizing each column of the comparison matrix A such that,

$$a_{ij}^{'} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad (2)$$

Further, each row in A′ is summarized into a vector with elements

$$a_i^{''} = \sum_{j=1}^{n} a_{ij}^{'} \quad (3)$$

Finally, the weight vector w is obtained as

$$W_s = a_i^{''}/n \quad (4)$$

Where n= number of factors for criteria

$$W_i = a_i^{''}/ m \quad (5)$$

Where m= number of factors for Alternatives

Step 4: Consistency Check

Consistency Ratio is calculated as

$$CR = CI / RI \quad (6)$$

where, CI = Consistency Index of comparison matrix

RI = Random Inconsistency

Consistency Index is calculated as

$$CI = \; = (\lambda_{max} - n) / (n - 1)$$

(7)

where, λ_{max} is the largest eigen value of matrix A.

Random Inconsistency is calculated as

$$RI = 1.98(n-2)/n \quad (8)$$

Step 5: Final score of alternatives (Selection Index) by Simple Additive Weighting (SAW)

Results obtained in the above steps are to be synthesized to achieve the overall weight of each decision alternative. In this case, the overall score of a candidate network is determined by the weighted sum of all the attribute values as

$$A_n = \sum_{i=1}^{imax} \left(W_{s_{n_i}}\right) * W_i \quad (9)$$

where A_n means the final score for candidate network 'n'; $W_{s_{n_i}}$ is the weight of candidate network n for the criteria i; W_i is the weight of criteria i and i_{max} is the total number of criteria.

To summarize, problem to be resolved is always at the topmost level in a typical hierarchy structure. In this case, the topmost level problem is "best access network selection". The subsequent level (second level) comprises the decision parameters, in this case, seven parameters related to network and MN. The solution alternatives (i.e., WLAN, WiMAX and UMTS) are in the bottom level. The relative magnitudes of decision parameters with respect to their parent problem are estimated through pairwise comparison based on subjective and objective factors. The definition of "best" involves subjective and objective aspects. Subjective factors are determined according to the preference of decision makers and objective parameters are determined by solving mathematical models without any consideration for decision makers' preferences. The smaller one of a pair is chosen as a unit, and the larger one is estimated as a multiple of that unit based on the perceived intensity of importance. The judgments are ranked on a 9-point scale in AHP (**Table 1**). When one element is less important than another, the comparison result equals the reciprocal of one of the numbers. The comparison results within each parent are presented in a square matrix to which we refer as the AHP matrix. The decision factors under a parent are arranged in the same order in row and column headings. When the i^{th} element in the column heading is compared to the j^{th} element in the row heading, the judgment is presented at the i^{th} row and j^{th} column. An example of an AHP matrix on "best access network selection" is shown in **Table 2**. It is observed that the diagonal elements of the matrix are 1, showing the elements' comparison with itself. The elements in the matrix are symmetric with respect to the diagonal elements as a result of inverted comparisons. The relative weights of the factors are achieved by calculating the eigen vector of the matrix with the eigen value that is closest to the number (n) of factors. AHP comparisons are subjective and judgement errors are to be detected by calculating a CI (eq. 7) of the AHP matrix and further comparing it with a RI (eq. 8), which is the average CI of a randomly generated reciprocal matrix. CI=0 indicates perfectly consistent matrix, otherwise, CI should be positive. Consistency Ratio (CR) is calculated and if it happens to be greater than 10%, adjustments of the comparisons are needed. This process is repeated level by level to the bottom of hierarchy.

4. Evaluation of AHP Design for Selection of Best Access Network

In any access network selection scheme, ABC means the network is selected on behalf of user and the user is connected to the best possible access network and enjoys high QoS at any time and any place. Therefore, ensuring a specific QoS is the goal of every access network selection algorithm in an integrated HetNets environment. As a result, QoS is the topmost level design goal of the AHP hierarchy for network selection. Hence, the decision criteria which are in the second level of hierarchy indicate QoS components in terms of throughput, timeliness, reliability and cost. Received Signal Strength (RSS) and coverage area indicates the availability of the network and are the triggering factors for the execution of VHO decision algorithm. Speed of the MN is critical factor in the access network selection scheme and frequent handoffs for high speed users are avoided by adopting coverage area. Bandwidth and NTL indicates throughput. Two parameters, delay and jitter decide timeliness. Bit Error Rate (BER) is used to define reliability.

In this network selection algorithm, availability is the precondition to other QoS deciding factors or criteria and hence network availability is the triggering factor. Only after the discovery of the available access network, the network performance, service class, and decision maker's preference are estimated. As UMTS could always be on, the problem is about detecting the availability of WLAN and WiMAX. The user is considered to be in the coverage of WLAN or WiMAX, if the RSS of WLAN or WiMAX is larger than the RSS threshold (i.e., –80 dBm). We assume that when the RSS is below a certain interface sensitivity level, the MN is unable to communicate with the WLAN Access Point (AP), or WiMAX Base Station (BS) and threshold value is the minimum level of RSS required for the active application running on a MN to perform satisfactorily during the process of handoff [25]. Simulation parameters are used as in [25,26] which are similar to the characteristics of the commercial services of WLAN and WiMAX.

The network selection algorithm which is based on various decision criteria collects other QoS information from the network and MN to determine whether to hand off to WLAN or WiMAX; otherwise, the network selection algorithm keeps UMTS connected. The process of VHO decision is actually a trade-off between network performance of the available network alternatives, decision criteria and application traffic type running on a MN.

4.1 Simulation Scenario

Goal of decision hierarchy is to select always best connected network by considering seven decision criteria such as Speed of the MN, Bandwidth of the target access network, NTL, Initial Connection establishment delay, Jitter, BER and Cost of usage of the access network and the available decision alternatives are WLAN, UMTS and WiMAX. Speed of the MN and NTL are considered as objective parameters other factors being subjective [21,22,23].

Simulation scenario consists of two WiMAX BSs, two Wireless Fidelity (Wi-Fi) APs, UMTS BS, a MN and a Correspondent Node (CN) as shown in Fig. 3. The AP's and BS's are connected to the CN through Layer 3 Router. It is assumed that the MN is equipped with multiple interfaces and moves in a straight line in the direction as shown in Fig. 3. We are considering four locations for the availability of access networks. All three access networks are available at point A, only UMTS is available at point B, UMTS and WLAN networks are available at point C and WiMAX and UMTS networks are available at point D. At the start of simulation, the MN is connected to WLAN at point C and transfer of data is from MN to CN through its AP. Then, MN starts heading in the direction of the point A and point D and on its way goes on detecting different access networks. AHP based multi-criteria VHO algorithm decides priority of influencing factors and the decision criteria based on the location for different traffic types such as streaming video, conversational, interactive and background type to make handoff decision so as to get ABC network.

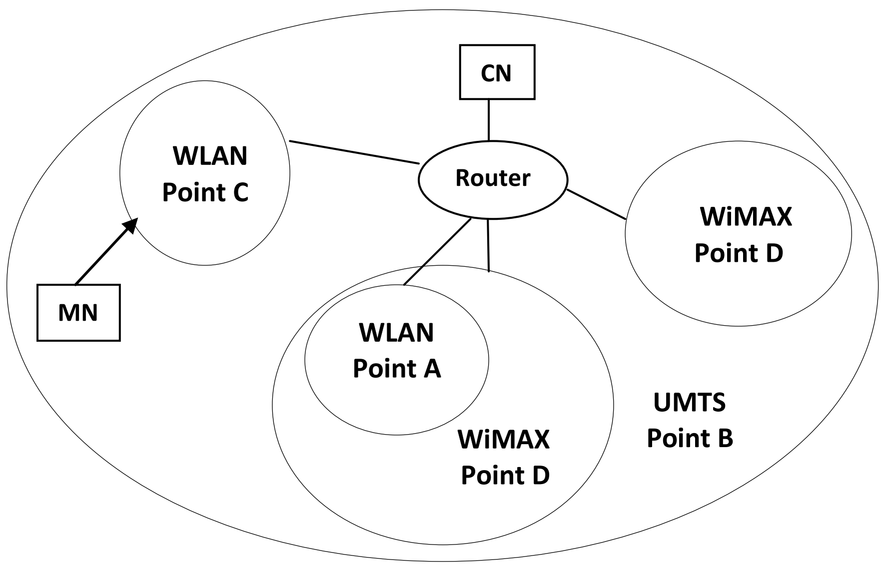

Fig. 3. HetNets Scenario for selection of ABC network

4.2 Design of First level AHP matrix for Streaming Video Traffic

Ranking of Criteria and Alternatives in AHP is done with pairwise comparisons and judgments are ranked on a 9-point scale (**Table 1**). These pairwise comparisons are carried out for all influencing factors to be considered during VHO decision making process.

Table 1. Ranking of Criteria and Alternatives

Intensity of importance	Verbal scale	Explanation
1	Equal importance	Two elements contribute equally
3	Moderate importance	Experience and judgment favour one element over another
5	Strong importance	An element is strongly favoured
7	Very strong importance	An element is strongly dominant

9	Extreme importance	An element is favoured by at least an order of magnitude
2,4,6,8	Intermediate values	Used to compromise between two judgments

First level AHP matrix (table) decides priority of influencing factor and the decision criteria for streaming video traffic is as given below:

(Speed = NTL) > (Bandwidth = Jitter) > (Initial Delay) > (Cost) > (BER)

Speed and NTL are equally and extremely important in the VHO decision making process during the transmission of streaming video traffic. Bandwidth and Jitter have very strong importance and Initial Delay, Cost and BER are strongly, moderately and equally important. Hence, the Scores assigned for QoS parameters are

Speed = NTL = 9, Bandwidth = Jitter = 7, Initial Delay = 5, Cost = 3 and BER = 1.

We have total five factors.

$$I = \frac{Sh - Sl}{N} = 2 \text{ (rounded)} \tag{10}$$

Where, $S_h = 9$ and $S_l = 1$ are the highest and lowest possible score for each criterion and N = 5 is the total number of criteria.

Using above assignments and the fundamental scale for AHP, first level AHP matrix [19,20] is derived as

Matrix elements are represented as 'a_{i*j}', where i= row number and j=column number.

- First row elements a_{1j} :
  a_{11} = (weight of speed criteria-weight of speed criteria)+1.
  = (9-9)+1 = 1

- Second row elements a_{2j}
  a_{21} = (weight of bandwidth criteria-weight of bandwidth criteria)+1.
  = (7-9)-1 = -3

If the subtraction result comes out to be negative, (-1) is to be added to the negative result instead of (+1) and reciprocal of the result ignoring negative sign will be our matrix element. Hence, $a_{21} = 1/3$

Similarly, all other elements of the matrix are shown in Table 2 and normalized values are obtained as shown in Table 3.

Table 2. First level AHP Matrix for deciding relative priority of influencing factors for streaming traffic

a_{ij}	Speed	BW	NTL	Initial Delay	Jitter	BER	Usage Cost
Speed	1	3	2	5	3	9	7
Bandwidth	1/3	1	1/3	3	1	7	5
NTL	1/2	3	1	5	3	9	7
Initial Delay	1/5	1/3	1/5	1	1/3	5	3
Jitter	1/3	1	1/3	3	1	7	5
BER	1/9	1/7	1/9	1/5	1/7	1	3
Usage Cost	1/7	1/5	1/7	1/3	1/5	1/3	1

Table 3. Normalized Table

a'_{ij}	Speed	BW	NTL	Initial Delay	Jitter	BER	Usage Cost	Priority vector (W_s)
Speed	0.3588	0.3458	0.4854	0.2852	0.3458	0.2348	0.2258	0.3259
BW	0.1794	0.1153	0.0809	0.1711	0.1153	0.1826	0.1613	0.1362
NTL	0.1794	0.3458	0.2427	0.2852	0.3458	0.2348	0.2258	0.2672
Delay	0.0718	0.0384	0.0485	0.0570	0.0384	0.1304	0.0968	0.0694
Jitter	0.1196	0.1153	0.0809	0.1711	0.1153	0.1826	0.1613	0.1362
BER	0.0399	0.0165	0.0270	0.0114	0.0165	0.0261	0.0968	0.0338
Cost	0.0513	0.0231	0.0347	0.0190	0.0231	0.0087	0.0323	0.0279

4.3 Design of Second level AHP Matrix for Streaming Video Traffic

The second level AHP matrix decides the priority of each access network based on the objective factors such as Speed and NTL and subjective factors such as Bandwidth, Jitter, Delay, BER and Usage cost. Normalization matrix, priority matrix and CR have been computed for all factors in a similar fashion.

Speed of the MN is converted to a 9-point scale for AHP matrix formation and is varied from 0 to 100 kmph. WLAN, UMTS and WiMAX support mobility up to 30-35 kmph, 90-100 kmph and 150 kmph respectively [22]. Hence, the 9-point conversion of speed for each network can be done as shown in eq. (11) below.

$$m_{WLAN} = 9 - (speed \times 8)/30$$
$$m_{UMTS} = 9 - (speed \times 8)/90$$
$$m_{WiMAX} = 9 - (speed \times 8)/130 \quad (11)$$

Table 4 indicates that the values for m_{WLAN} are negative for the speed above 30 kmph. As AHP matrix cannot handle negative values, previous values are repeated for 40 kmph onwards.

Table 4. 9-point conversion of speed for each network

Speed (kmph)	m_{WLAN}	m_{UMTS}	m_{WIMAX}
0	9	9	9
10	6.333	8.111	8.385
20	3.667	7.222	7.769
30	1	6.333	7.1538
40	-1.667	5.444	6.538
50	-4.333	4.556	5.923
60	-7	3.667	5.3076
70	-9.667	2.778	4.6923
80	-12.33	1.889	4.0769
90	-15	1	3.46
100	-17.67	0.111	2.8461

Second level AHP matrix for deciding priority of each network on the basis of speed is as shown by eq. (12) and **Table 5**:

$$A = \begin{bmatrix} 1 & (m_{wimax}/m_{umts}) & (m_{wimax}/m_{wlan}) \\ (m_{umts}/m_{wimax}) & 1 & (m_{umts}/m_{wlan}) \\ (m_{wlan}/m_{wimax}) & (m_{wlan}/m_{umts}) & 1 \end{bmatrix} \tag{12}$$

Table 5. Second level AHP Matrix for deciding relative priority of networks for Speed

a_{ij}	WiMAX	UMTS	WLAN	Priority vector (W_1)
WiMAX	1	1	1	0.3333
UMTS	1	1	1	0.3333
WLAN	1	1	1	0.3333

CR1 = -3.8284e-016

Similarly, the second level AHP matrix to decide the priority of each access network based on the subjective factors such as Bandwidth and Jitter is shown in **Table 6**.

Table 6. Second level AHP Matrix for deciding relative priority of networks for Bandwidth & Jitter

a_{ij}	WiMAX	UMTS	WLAN	Priority vector (W_2 & W_5)
WiMAX	1	3	1/3	0.2605
UMTS	1/3	1	1/5	0.1062
WLAN	3	5	1	0.6333
				CR2 =0.0332

NTL is also converted into a 9-point scale for AHP matrix formation as shown in eq. (13).

$$\begin{aligned} N_{WLAN} &= 4 - (NTL \times 4)/100 \\ N_{UMTS} &= 9 - (NTL \times 4)/100 \\ N_{WiMAX} &= 5 - (NTL \times 4)/100 \end{aligned} \quad (13)$$

(4NTL)/100 signify the uniform distribution (in percentage) of NTL.

For NTL= 40%, the 9-point conversion is as shown in eq. (14).

$$\begin{aligned} N_{WLAN} &= 2.4000 \\ N_{UMTS} &= 7.4000 \\ N_{WiMAX} &= 3.4000 \end{aligned} \quad (14)$$

Second level AHP matrix for deciding priority of each network on the basis of NTL is designed as shown in eq. (15) and has been tabulated as depicted in **Table 7**:

$$A = \begin{bmatrix} 1 & (N_{wimax}/N_{umts}) & (N_{wimax}/N_{wlan}) \\ (N_{umts}/N_{wimax}) & 1 & (N_{umts}/N_{wlan}) \\ (N_{wlan}/N_{wimax}) & (N_{wlan}/N_{umts}) & 1 \end{bmatrix} \quad (15)$$

Substituting Values, matrix A can be rewritten as shown in eq. (16),

$$A = \begin{bmatrix} 1.0000 & 0.4595 & 1.4167 \\ 2.1765 & 1.0000 & 3.0833 \\ 0.7059 & 0.3243 & 1.0000 \end{bmatrix} \quad (16)$$

Table 7. Second level AHP Matrix for deciding relative priority of networks for NTL

a_{ij}	WiMAX	UMTS	WLAN	Priority vector (W_3)
WiMAX	1.0000	0.4595	1.4167	0.2576
UMTS	2.1765	1.0000	3.0833	0.5606
WLAN	0.7059	0.3243	1.000	0.1818

CR3= -1.1485e-015

Further, the second level AHP matrix for delay, BER and cost is depicted in **Table 8, Table 9** and **Table 10**.

Table 8. Second level AHP Matrix for deciding relative priority of networks for delay only

a_{ij}	WiMAX	UMTS	WLAN	Priority vector (W_4)
WiMAX	1	3	1/3	0.2431
UMTS	1/3	1	1/7	0.0882
WLAN	3	7	1	0.6687

Table 9. Second level AHP Matrix for deciding relative priority of networks for BER only

a_{ij}	WiMAX	UMTS	WLAN	Priority vector (W_6)
WiMAX	1	1	1	0.3333
UMTS	1	1	1	0.3333
WLAN	1	1	1	0.3333

Table 10. Second level AHP Matrix for deciding relative priority of networks for cost only

a_{ij}	WiMAX	UMTS	WLAN	Priority vector (W_7)
WiMAX	1	1/3	1/5	0.1062
UMTS	3	1	1/3	0.2605
WLAN	5	3	1	0.6333

As per eq. (4) & (5), weight vector W is obtained as

$$W = [\ W_1 \quad W_2 \quad W_3 \quad W_4 \quad W_5 \quad W_6 \quad W_7\ ] \tag{17}$$

For constant NTL= 40% and speed = 0 kmph, final score is calculated using eq. (9) as

Table 11. Final Score calculation (Selection Index) using SAW

WiMAX	UMTS	WLAN
0.3092	0.2732	0.4176

Results in **Table 11** indicate highest score for WLAN and hence it is selected for streaming video traffic type of transmission out of three available access networks. Similarly, selection index is calculated by varying speed between 10 to 100 kmph keeping NTL constant at 40% (**Table 12**).

Table 12. Access Network Selection Speed Vs Selection Index (SI)

Speed/SI	0	10	20	30	40	50	60	70	80	90	100
WiMAX	0.3092	0.3204	0.3366	0.3881	0.4198	0.4274	0.4534	0.4744	0.4991	0.5287	0.6782
UMTS	0.2732	0.2804	0.2909	0.3304	0.2968	0.2901	0.2669	0.2483	0.2264	0.2001	0.1822
WLAN	0.4176	0.3392	0.3725	0.2815	0.2834	0.2825	0.2796	0.277	0.2746	0.2713	0.1397

In a similar fashion, all AHP-SAW steps have been evaluated for conversational, background and interactive type of traffic.

5. Experimental Results and Discussions

This section presents simulation results related to network selection between WiMAX, UMTS and WLAN for different traffic types. MATLAB and ns-2 have been used for simulation purpose. The selection of the network differs depending on applications which are running on the MN. One of the parameters NTL or the speed of the MN is varied and the relative closeness to the ideal solution (network selection index) is measured keeping the other parameter (NTL or speed) constant.

Case I: Choice of Network at point A for Streaming Video Type of Traffic

As shown in **Fig. 3**, all three access networks are available at point A. **Fig. 4** indicates that WLAN is a network of choice when the MN is moving at a speed between 0-22 kmph as it supports higher mobility than UMTS and WiMAX. The streaming traffic class requires bandwidth in the range of 2-20 Mbps. If bandwidth is the priority, then network preference is WLAN>WiMAX>UMTS. WLAN is also preferred by considering initial connection establishment time and usage cost. When speed of the MN is greater than 22 kmph, final score of WLAN decreases as it cannot support further mobility and WiMAX emerges out to be the best access network. Hence, handoff takes place at 22kmph from WLAN to WiMAX and it remains the best access network till 100kmph. UMTS is never selected for a streaming video type of traffic.

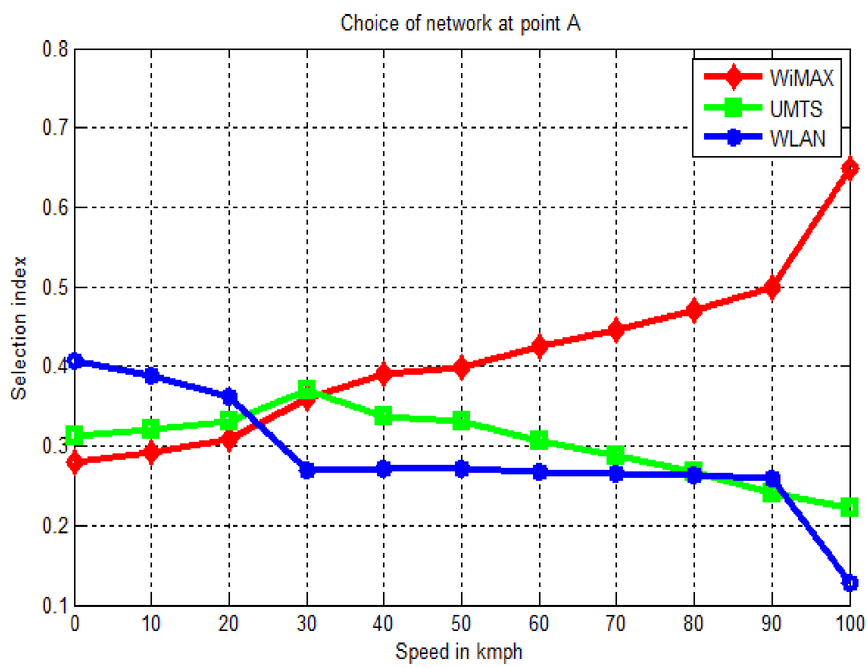

Fig. 4. Choice of Network at Point A for streaming video (NTL = 40 %)

Case II: Choice of Network at Point C for Conversational Type of Traffic

As shown in simulation scenario, the available networks at point C are WLAN and UMTS. WLAN provides higher mobility than UMTS for the MN moving between 0 to 25 kmph. When speed increases beyond 25 kmph, final score of WLAN decreases as WLAN does not support mobility greater than 25kmph and hence handoff takes place from WLAN to UMTS. UMTS remains a network of choice for the range of 25 to 100kmph.

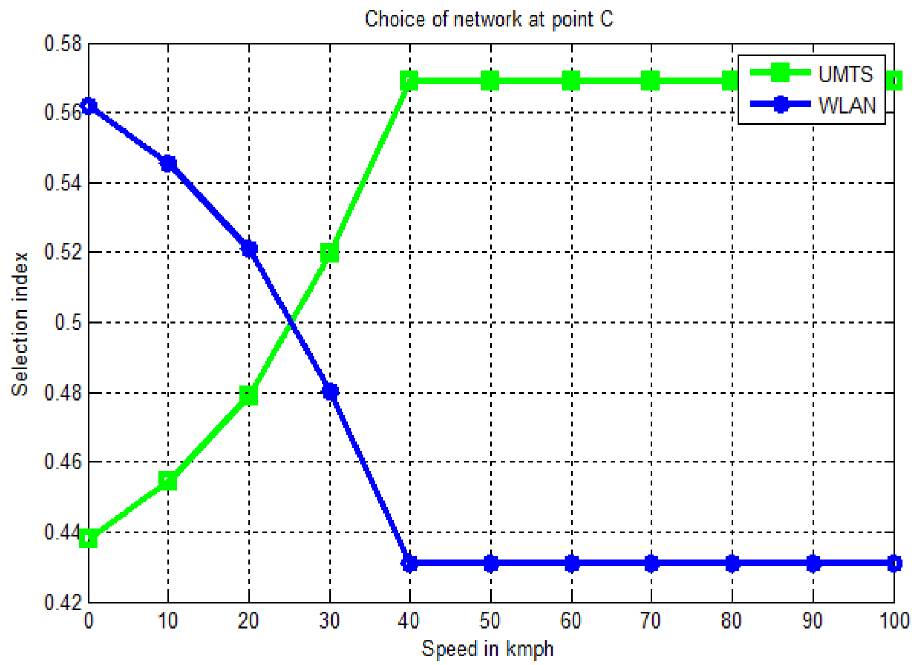

Fig. 5. Choice of Network at point C for conversational traffic (NTL = 40%)

Case III Choice of Network at Point A for Interactive Type of Traffic

As shown in simulation scenario, all three networks are available at point A. NTL is kept at 40%. Bandwidth is unspecified for interactive type of traffic class.

So, all three networks have the same priority for bandwidth. For this class of application, the vertical handoff is never performed and data is transmitted through currently activated network interface [21]. Delay and jitter performance is better for WiMAX. Hence, final score of WiMAX is higher than UMTS and WLAN and is selected throughout.

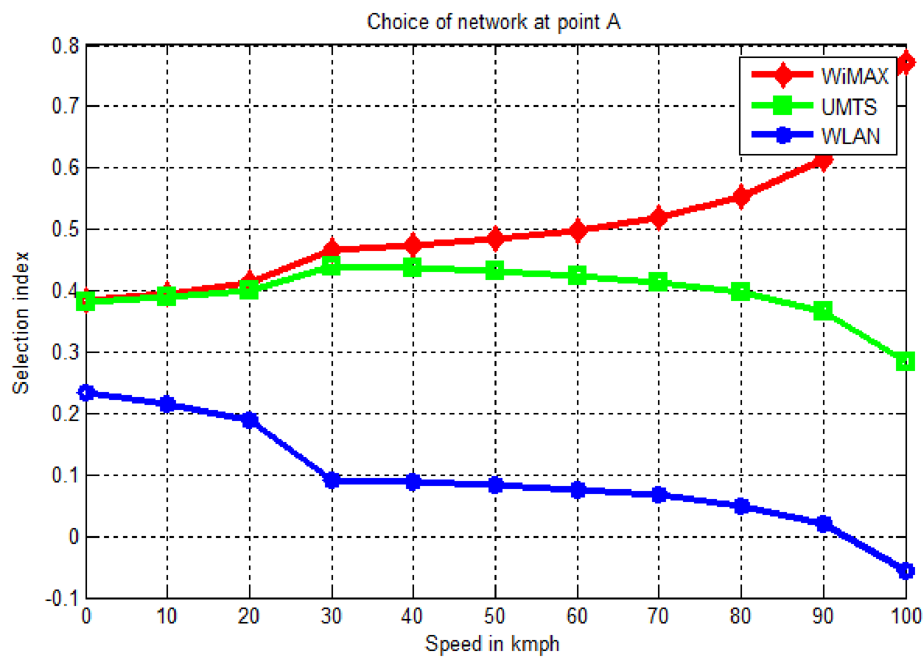

Fig. 6. Choice of Network at point A for Interactive Traffic (NTL = 40%)

Case IV Choice of Network at Point A for Background Type of Traffic

As per the simulation scenario, all three networks are available at point A. Background class required less bandwidth in kbps and hence UMTS is preferred between 0-30 kmph. Beyond 30kmph, final score of WiMAX increases and vertical handoff takes place from UMTS to WiMAX by considering all other QoS parameters. WLAN never gets selected.

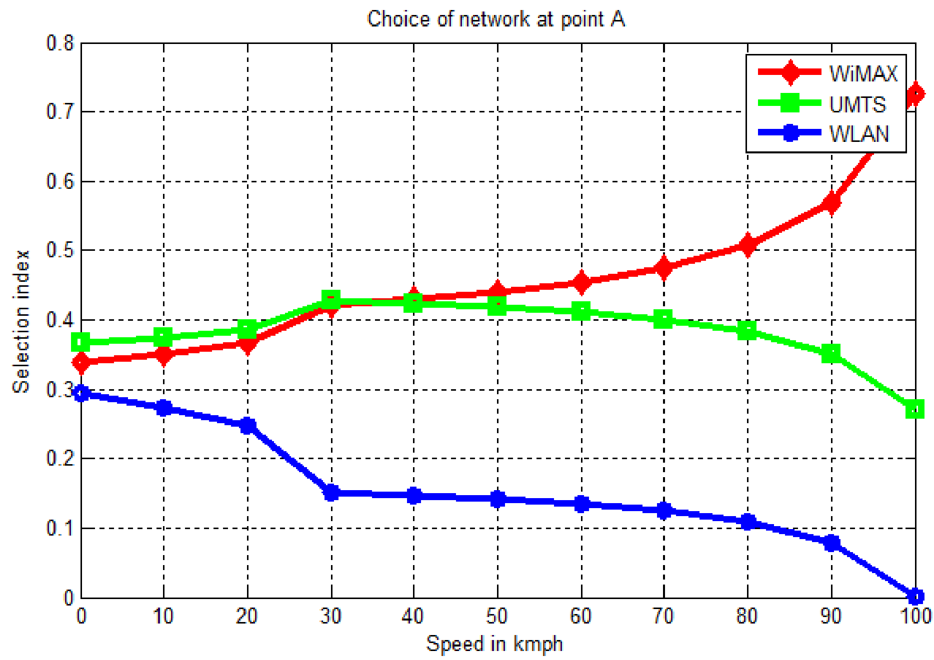

Fig. 7. Choice of Network at point A for Background Traffic (NTL = 40%)

All these results are summarized in **Table 12** below.

Table 12. Access network selection

Point	Available Networks	NTL (%)	Speed (kmph)	Traffic Type	Selected Access Network
A	WiMAX,WLAN,UMTS	40	0-100	Streaming	0-22 kmph WLAN 22-100 kmph WiMAX
C	WLAN,UMTS	40	0-100	Conversational	0-25 kmph WLAN 25-100 kmph UMTS
A	WiMAX,WLAN,UMTS	40	0-100	Interactive	WiMAX Throughout
A	WiMAX,WLAN,UMTS	40	0-100	Background	0-30 kmph UMTS 30-100kmph WiMAX

6. Conclusion

This paper presents a very simple and straightforward network selection scheme for the integration of WLAN, WiMAX and UMTS which guarantees the best QoS while preventing frequent handoffs. Analytic hierarchical approach effectively exploits the hierarchy and pairwise comparison thereby eliminating rigorous and CPU intensive mathematical computations and processing time. AHP-SAW ranks the access network alternatives efficiently by evaluating the decision criteria for the corresponding traffic class quantitatively. AHP ensures QoS due to its inherent application specific design. Unlike other schemes proposed in the literature, we considered maximum number of decision parameters and weighted them based on their importance to IMT 2000 QoS traffic classes.

The simulation results reveal that the simple and novel access network selection technique can efficiently decide the trade-off among traffic class, MN parameters and network conditions. Further, the priorities of decision parameters can be decided based on their approximate comparisons rather than exact values in the heterogeneous system with three network alternatives indicating simpler implementation.

Hence, we can conclude that the proposed hierarchical design, evaluation and simulation give optimum solution for access network selection. It completely eliminates the handoff failures and unnecessary handoffs and hence ping-pong effect. Graphical results and analysis are also consistent with the established and proven concepts related to wireless access networks when it comes to characteristics of the traffic classes. Like, for lower mobility, WLAN has been consistently selected as a network of choice. WiMAX is always preferred for greater mobility though it has lesser coverage area than UMTS. UMTS is considered to be the best network in case of high NTL.

Future research will design and evaluate this novel scheme in more comprehensive situations with many wired and wireless access network alternatives and decision criterias by using 802.21 functionality of Network Simulator (ns) version 2.29.

References

[1] Akyildiz, J. Xie, S. Mohanty, "A survey of mobility management in next-generation all-IP-based Wireless systems," *IEEE Wireless Communications*, 11 (4), 16–28, 2004. Article (CrossRef Link)

[2] E. Gustafsson, A. Jonsson, "Always best connected," *IEEE Wireless Communications*, vol. 10, no.1, pp. 49-55, 2003. Article (CrossRef Link)

[3] E Stevens-Navarro, U Pineda-Rico, J Acosta-Elias, "Vertical handover in beyond third generation (3G) wireless networks," *International Journal of Future Generation Communication Networks*, vol. 1, pp. 1–8, 2010.

[4] B. R. Chandavarkar, Dr. G. Ram Mohan Reddy, "Improvement in Packet Drop during Handover between WiFi and WiMax," in *Proc. of International Conference on Network and Electronics Engineering IPCSIT*, IACSIT Press, Singapore, vol. 11, pp. 71-75, 2011.

[5] BS Ghahfarokhi, N Movahhedinia, "A context-aware handover decision based on user perceived quality of service trigger," *Wireless Communications and Mobile Computing, Wiley*, 11(6), 723–741, 2011. Article (CrossRef Link)

[6] Pranjali Bhandari, Poonam Jaswani, Shivani Singh, Sahana Bhosale, R.D. Daruwala, "Graphical Analysis of Parameters Related to Vertical Handover Optimization between Cellular Networks and WLANs," in *Proc. of International Conference on Information, Communication and Embedded Systems*, vol.1, pp. 84-91, Chennai, India, 2012.

[7] Pranjali Bhandari, Poonam Jaswani, Shivani Singh, Sahana Bhosale, R.D. Daruwala, "Graphical Analysis of Parameters Related to Vertical Handover Optimization between

Cellular Networks and WLANs," *International Journal of Research in Wireless Sensor Networks IJRWSN*, vol. 1, no.1, 2012.

[8] Johann Marquez-Barja, Carlos T. Calafate, Juan-Carlos Cano, Pietro Manzoni, "An overview of vertical handover techniques: Algorithms, protocols and tools," *Computer Communications*, vol. 34, pp. 985-997, 2011. Article (CrossRef Link)

[9] Xiaohuan Yan , Y. Ahmet Sekercioglu, Sathya Narayanan, "A survey of vertical handover decision algorithms in Fourth Generation heterogeneous wireless networks," *Elsevier Computer Communications*, 54, 1848-1863,2010. Article (CrossRef Link)

[10] Mariem Zekri, Badii Jouaber, Djamal Zeghlache, "A review on mobility management and vertical handover solutions over heterogeneous wireless networks," *Computer Communications*, no. 35, pp. 2022-2068, 2012. Article (CrossRef Link)

[11] Sahana Bhosale and Dr. R.D.Daruwala.: Simulation of Vertical Handover between WiFi and WiMax and its Performance Analysis – An Installation Perspective," *Proceedings of IEEE INDICON Engineering Sustainable Solutions*, Hyderabad, India, 2011.

[12] Sahana Bhosale and R.D.Daruwala, "Investigations on IEEE 802.21 based Media Independent Handoff Algorithm for Access Network Selection between WiFi and WiMAX," *International Journal of Scientific & Engineering Research*, vol. 4, no. 2, May 2013, ISSN 2229-5518.

[13] Kantubukta Vasu, Sumit Maheshwari, Sudipta Mahapatra, Cheruvu Siva Kumar, "QoS-aware fuzzy rule-based vertical handoff decision algorithm incorporating a new evaluation model for wireless heterogeneous networks," *EURASIP Journal on Wireless Communications and Networking*, 2012. Article (CrossRef Link)

[14] Koksalan, M., Wallenius, J., and Zionts, S, "Multiple Criteria Decision Making: From Early History to the 21st Century*," World Scientific*, Singapore, 2011.

[15] Patrovi, F.Y, "Determining what to benchmark: An analytic hierarchy process approach," *International Journal of Operational Project Management.,* vol. 14, no.6, pp. 25–39, 1994. Article (CrossRef Link)

[16] Isakson, Lennart, Fiedler and Markus, "Seamless connectivity in WLAN and cellular networks with multi-criteria decision making," in *Proc. of IEEE 3rd Euro-NGI conference on Next Generation Internet Networks*, Trondheim, Norway, 2007. Article (CrossRef Link)

[17] Song, Q, Jamilipour, A, "Network Selection in an Integrated Wireless LAN and UMTS Environment Using Mathematical Modeling and Computing Techniques," *IEEE Wireless Communications*, 2005. Article (CrossRef Link)

[18] Steuer, R.E, "Multiple Criteria Optimization: Theory, Computation and Application," John Wiley, New York, 1986. Article (CrossRef Link)

[19] Saaty, T.L, "The analytical hierarchy process—what it is and how it is used," Mathematical Modeling, vol. 9, pp. 161–176, 1987. Article (CrossRef Link)

[20] Saaty, T.L, "How to make a decision: The analytic hierarchy process," *Interfaces*, vol. 24, no. 6, pp. 19–43, 1984. Article (CrossRef Link)

[21] Saaty, T.L, "Exploring optimization through hierarchies and ratio scales," Socio-Economic Planning Sciences, vol. 20, no. 6, pp. 355–360, 1986. Article (CrossRef Link)

[22] Dhar, Sourav Ray, A Bera, R Sur S.N, and Ghosh, D, "A Complete Simulation of Intra Vehicle Link Through Best Possible Wireless Network," *International Journal of Computer and Electrical Engineering*, vol. 2, no. 4, pp. 673-681, 2010. Article (CrossRef Link)

[23] Dhar Sourav, Ray Amitav, Bera Rabindranath, "Design, Simulation and Sensitivity Analysis of Vertical Handover Algorithm for Vehicular Communication," *International Journal of Computer Science and Software Technology*, vol. 3, no.2, 2010.

[24] 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, no.1, pp.24–34, 2011. http://ijecct.coe.edu.my/journal/index.php/ijecct/article/view/50/27

[25] A. Majlesi and B. H. Khalaj, "An adaptive fuzzy logic based handoff algorithm for hybrid networks," in *Proc. of 6th International Conference on Signal Processing*, vol. 2, Aug. 2002, pp. 1223 – 1228. Article (CrossRef Link)

[26] A. H. Zahran, B. Liang, and A. Saleh, "Signal threshold adaptation for vertical handoff in heterogeneous wireless networks," *ACM/Spring Mobile Networks and Applications (MONET), Special Issue on Soft Radio Enabled Heterogeneous Networks*, vol. 11, no. 4, pp. 625-640, 2006.

[27] M. Kassar, B. Kervella, G. Pujolle, "Architecture of an intelligent inter-system handover management scheme," in *Proc. of IEEE Future Generation Communication and Networking Conference*, vol. 1, pp. 332–337, 2007. Article (CrossRef Link)

[28] M. Kassar, B. Kervella, G. Pujolle, "Autonomic-oriented architecture for an intelligent handover management scheme," in *Proc. of 6th IEEE Annual Communication Networks and Services Research Conference*, 2008, pp.139–146.

[29] M. Kassar, B. Kervella, G. Pujolle, "An overview of vertical handover decision strategies in heterogeneous wireless networks," *Elsevier Computer Communications*, 31 (10) (2008), 2607-2620. Article (CrossRef Link)

[30] L. Xia, J. Ling-Ge, H. Chen, L. Hong-Wei, "An intelligent vertical handoff algorithm in heterogeneous wireless networks," in *Proc. of IEEE International Conference on Neural Networks and Signal Processing*, 2008, pp. 550–555.

[31] E. Stevens-Navarro, Y. Lin, V.W.S. Wong, "An MDP-based vertical handoff decision algorithm for heterogeneous wireless networks," *IEEE Transactions on Vehicular Technology*, 57 (2) (2008) 1243–1254. Article (CrossRef Link)

[32] H. Liao, L. Tie, Z. Du, "A vertical handover decision algorithm based on fuzzy control theory," in *Proc. of IEEE International Multi-Symposiums on Computer and Computational Sciences*, Los Alamitos, CA, USA, vol.2, 2006, pp.309–313.

Sahana Bhosale is currently Associate Professor in the Department of Electronics and Telecommunication Engineering at Bharati Vidyapeeth's College of Engineering for Women, Pune, India. She received her Bachelor's in Electronics and Telecommunication Engineering (B.E) from Government College of Engineering, Amravati, India followed by Masters in Electronics Engineering (M.E) with Computer specialization from Government College of Engineering, Pune, India. Currently she is pursuing her PhD in the area of Fourth Generation (4G) Wireless Access Networks at Veermata Jijabai Technological Institute, Mumbai, India. She has more than 13 years of experience in academics and industry. She has been delivering courses in the area of Networking, Telecommunications and Wireless to under-graduate and post-graduate engineering students since last 11 years. She has supervised more than 40 thesis at the Master's level. Recently she has received Best Paper Award at the prestigious IEEE International Conference INDICON 2011 which is a flagship conference of IEEE India Council.

Rohin Daruwala is a Professor of Electronics Engineering at Veermata Jijabai Technological Institute, Mumbai, India. He received his Bachelor of Engineering (B.E) from National Institute of Technology (NIT), Surat, India and Master of Engineering and PhD from Mumbai University, India. He has more than 25 years of experience in teaching undergraduate & post graduate students. His research interests include Digital Design, Computer architecture, Microprocessor Systems Design and Wireless Networks. He serves as a member of All India Board of Post-Graduate Education and Research in Engineering & Technology which is a constituent body of All India Council for Technical Education (AICTE). He, along with his students, is the recipient of prestigious IEEE Bendix award for two times. Dr. Daruwala is an active member of IEEE and IEEE Computer Society.