A FAHP Weighting Scheme for System Attributes in Heterogeneous Wireless Networks

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***Abstract*—In a heterogeneous wireless network, different wireless access technologies with different operating parameters coexists in an overlay fashion. These wireless networks are deployed in order to provide different type of services to Mobile Stations (MSs) equipped with multiple interfaces, based on the principle of Always Best Connected (ABC) network. In such a dynamic environment, an MS can seamlessly switch from one wireless Access Network (AN) to another to guarantee continuity and quality of the current session. This is where the need for intelligent and efficient Vertical Handoffs (VHOs) between technologies in a heterogeneous wireless environment becomes apparent. This paper presents the design and the detailed calculations of a novel weighting mechanism for the system attributes in heterogeneous wireless networks with applications to VHO. A Fuzzy based Analytic Hierarchy Process (FAHP) is used to calculate the weights, due to its capability to handle inherent uncertainty and vagueness which is present in the subjective preference evaluations of end-users. The mechanism is designed for four different traffic classes and takes into account the Quality of Service (QoS) requirements for each class.**

Keywords—fuzzy logic; handoffs; MADM; heterogeneous wireless networks; Fuzzy Analytic Hierarchy Process;

I. INTRODUCTION

During recent years, the need to provide global connectivity with efficient ubiquitous computing at anyplace, and anytime has significantly increased [1]. The latest innovations in wireless access technology along with the fast evolution of MSs, enables the development of a pervasive environment where an MS can be offered simultaneous connectivity from different networks and can receive different types of services in an uninterrupted fashion, independent of its own type, locations and types of networks [2]; the ultimate goal is to maintain a satisfactory end-user experience by performing intelligent and efficient handoffs. Traditional handoff schemes such as Received Signal Strength (RSS) based do not take into account factors such as the Quality of Service (QoS), end-user preferences, MS-mobility, and the location and application contexts while performing these handoff decisions. Selection of ABC network while considering the QoS requirements for different traffic classes and end-user's satisfaction has recently become an important research topic. Since multiple criteria may be involved when ranking a target network, single criterion based ranking schemes may not generate optimal network selection decisions. On the other hand, all handoff algorithms utilize a sort of weighting mechanism for assigning proper weights to system attributes. Precise weighting of different attributes is an essential task and should be done carefully in order to improve the accuracy of handoff procedure. 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 that use multi-criteria, performs weight assignments of network parameters either manually or by means of the conventional Analytical Hierarchical Process (AHP). Manual weight assignment do not consider how much of a weight is needed for a certain network parameter, which can lead to a degraded VHO performance if one parameter is given higher weight as compared to another, especially during an ongoing session such as a Voice over IP (VoIP) conversations where achieving a minimum level of QoS is essential. Despite its popularity, the conventional AHP methodology is often criticized for its failure to effectively handle the intrinsic imprecision and fuzziness associated with the mapping of the user's preference to crisp numbers. 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 [3] and [4]. The Artificial Intelligence (AI) scheme in [3], which is based on a hybrid of parallel fuzzy-logic-system, multiple-criteria decision making and Genetic Algorithm (GA), is developed to provide adaptive, flexible, and scalable solution to the VHO decision problem. The decision phase uses three parallel fuzzy-logic subsystems. The normalized outputs of these subsystems along with their importance weights, optimized using GAs, are fed into a multi-criteria decision making system, which utilizes an enhanced version of Simple Multi-Attribute Rate Technique (SMART). The results show an increase percentage of satisfied users. However, the proposed scheme is limited to only four different criteria and doesn't take into consideration other important decision factor like loading conditions of the network. Furthermore, single-objective GAs are used to optimize each objective weight independently rather than utilizing a multi-objective utilization method to find optimal weights jointly, which could have resulted in an improved performance. A VHO algorithm based on fuzzy logic in conjunction with Grey Prediction Theory (GPT) is presented in [4]. The GPT takes 4 sampled RSSs as input and is used to predict the future RSS values to trigger the handoff initiation process. Fuzzy logic based Quantitative Decision Algorithm (FQDA) is used to quantitatively evaluate RSS, available bandwidth, and usage cost of the candidate networks. The FQDA produces a Quantitative Decision Value (QDV) for each candidate network that indicates the probability of a certain candidate becoming the target of handoff. The final handoff decision is made based on the resulted QDVs. The proposed approach doesn't take into consideration other factors like security, user preferences, and other QoS-related parameters.

In this paper, a weighting method for the heterogeneous networks' attribute is proposed that can be used to perform handoff necessity estimations and target network selection decisions while considering the intrinsic ambiguity and fuzziness present in the network-attributes' weights selection by the end-users. This task is accomplished by utilizing Fuzzy Analytical Hierarchy Process (FAHP) [5] weighting scheme to determine the required weight for each attribute in a dynamic wireless environment. Although AHP-based weighting schemes are commonly utilized with different Multi Attribute Decision Making (MADM) algorithms to rank the network alternatives, they failed to reflect the human thinking style. The traditional AHP method is also criticized due to its use of unbalanced scale of judgments and its inability to adequately handle the inherent uncertainty and imprecision of a wireless environment. To overcome all these shortcomings, the proposed approach utilizes FAHP to calculate the necessary weights of the network attributes to utilize interval preferences rather than fixed value preferences. The step-by-step details of the FAHP algorithm and how it can be used to calculate weights will be provided with numerical examples. FAHP is used to calculate the weights of a total of nine attributes that also includes a comprehensive set of network related QoS parameters based on the different types of traffic classes, namely, conversational, background, interactive and streaming. The proposed weighting scheme is integrated into a VHO procedure and its performance is evaluated using a comprehensive wireless simulation test-bed. Three networks, i.e., Wireless Local Area Network (WLAN), Wireless Metropolitan Area Network (WMAN), and Wireless Wide Area Network (WWAN), are implemented for the simulation.

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. Finally, concluding remarks are drawn in section V.

II. Proposed Scheme

The proposed FAHP weighting scheme is developed to provide weighting mechanism for our VHO scheme that is implemented to estimate the necessity of performing the VHO and the selection of a target network. The VHO scheme, in the first stage, measures the attributes from all networks in range and then the weights for each attribute are calculated with respect to the type of traffic. 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, i.e., network throughput, latency, jitter, and Packet Loss Ratio (PLR). With the exception of distance between the MS and the serving Point of Attachment (PoA), the same attributes are utilized in the target network selection module to determine the best target network. For more details on the design of our complete VHO scheme, the readers may refer to [6].

The end-users can specify their needs and preferences by assigning priority weights to each system attributes. Our scheme assigns higher weights to network RSS and QoS in order to maximize end-user's satisfaction. Furthermore, since QoS requirements vary for various types of traffic classes, different weights with respect to traffic types need to be calculated and assigned. The proposed scheme considers four different types of traffic classes with different characteristics and QoS demands as defined by 3GPP TS-23.107 specifications [7]. Note that the assignments and calculations of these weights can either be manual or automated and our proposed scheme is flexible and offers both manual and automated weight calculations using different techniques. Two levels of criteria are considered. The order of preference for level-1 criteria, as utilized in our design is: RSS, QoS, 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 can be assigned by the end user whereas the relative importance for the second-level, i.e., network throughput, latency, jitter and PLR, attributes are defined by our proposed scheme. Different requirements related to the QoS for the four traffic classes are taken into account as well.

We utilize a FAHP weighting scheme to calculate the weights of the nine attributes. Different from the conventional AHP algorithms, FAHP expresses the relative importance among the pair of decision factors via the Triangular Fuzzy Numbers (TFNs). A TFN is a special type of fuzzy number whose membership is defined by three real numbers as, $\tilde{x} = (l, m, u)$, where parameter m is the most promising value as it gives the maximal grade of the membership function, $\mu(x)$, and parameters l and u are the lower and upper bounds that limit the field of the possible evaluation [8]. The membership function of a TFN is given by:

$$\mu(x) = \begin{cases} \frac{(x-l)}{(m-l)} & x \in [l, m] \\ \frac{(u-x)}{(u-m)} & x \in [m, u] \\ 0 & otherwise \end{cases} \quad (1)$$

These TFNs and their reciprocal values are defined in Table 1.

Following are the steps involved for FAHP weight calculation in our proposed scheme:

1. In the first step, AHP matrices, containing pairwise comparisons of attributes, are obtained from multiple decision makers according to:

Table 1: TFNs and Reciprocal TFNs for FAHP Levels of Importance

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

$$A^p = [a_{ij}]^p_{n\times n} = \begin{bmatrix} a^p_{11} & a^p_{12} & \cdots & a^p_{1n} \\ a^p_{21} & a^p_{22} & \cdots & a^p_{2n} \\ \vdots & \vdots & & \vdots \\ a^p_{n1} & a^p_{n2} & & a^p_{nn} \end{bmatrix} \quad p = 1, 2, \ldots, t \qquad (2)$$

where p represents the number of decision makers, $i = j = 1, 2, \ldots, n$ and n is the number of attributes.

2. TFNs representing grades of multiple decision makers are obtained via the equation below:

$$l_{ij} = \min_p(a^p_{ij}), \quad m_{ij} = \frac{\sum_{p=1}^{t} a^p_{ij}}{p}, \quad u_{ij} = \max_p(a^p_{ij}) \qquad (3)$$

where $p = 1, 2, \ldots, t$ and $i = j = 1, 2, \ldots, n$

3. Establish the FAHP comparison matrix that contains TFNs representing pair-wise comparisons between the attributes at a certain level of hierarchy according to

$$\tilde{A} = (\tilde{a}_{ij})_{n\times n} = \begin{bmatrix} (1,1,1) & (l_{12}, m_{12}, u_{12}) & \cdots & (l_{1n}, m_{1n}, u_{1n}) \\ (l_{21}, m_{21}, u_{21}) & (1,1,1) & \cdots & (l_{2n}, m_{2n}, u_{2n}) \\ \vdots & \vdots & & \vdots \\ (l_{n1}, m_{n1}, u_{n1}) & (l_{n2}, m_{n2}, u_{n2}) & & (1,1,1) \end{bmatrix} \qquad (4)$$

where $(\tilde{a}_{ji}) = [\tilde{a}_{ij}]^{-1} = (l_{ij}, m_{ij}, u_{ij})^{-1} = (\frac{1}{u_{ij}}, \frac{1}{m_{ij}}, \frac{1}{l_{ij}})$

4. Weights of the attributes are acquired using Fuzzy Extent Analysis [14]. The value of the fuzzy synthetic extent w.r.t the i^{th} object is obtained by:

$$\tilde{S}_i = \sum_{j=1}^{n} \tilde{a}_{ij} \times \left[\sum_{i=1}^{n}\sum_{j=1}^{n} \tilde{a}_{ij}\right]^{-1} \qquad (5)$$

where $\sum_{j=1}^{n} \tilde{a}_{ij} = (\sum_{j=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij}, \sum_{j=1}^{n} u_{ij})$ and

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{n} \tilde{a}_{ij}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{n} u_{ij}}, \frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{n} m_{ij}}, \frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{n} l_{ij}}\right) \qquad (6)$$

5. Calculate the degree of possibility for a convex fuzzy number to be greater than k convex fuzzy numbers, $\tilde{S}_i$ $(i = 1, 2, \ldots, k)$, accroding to

$$V(\tilde{S} \geq \tilde{S}_i) = V[(\tilde{S} \geq \tilde{S}_1) \wedge (\tilde{S} \geq \tilde{S}_2) \ldots (\tilde{S} \geq \tilde{S}_k)]$$
$$V(\tilde{S} \geq \tilde{S}_i) = min\{V(\tilde{S} \geq \tilde{S}_i)\} \qquad (7)$$

where the degree of possibility of $\tilde{S}_1 \geq \tilde{S}_2$ and $\tilde{S}_2 \geq \tilde{S}_1$ is given by:

$$V(\tilde{S}_1 \geq \tilde{S}_2) = \begin{cases} 1 & m_1 \geq m_2 \\ 0 & l_2 \geq u_1 \\ \frac{l_2 - u_1}{(m_1 - u_1) - (m_2 - l_2)}, & otherwise \end{cases} \qquad (8)$$

and

$$V(\tilde{S}_2 \geq \tilde{S}_1) = \begin{cases} 1 & m_2 \geq m_1 \\ 0 & l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise \end{cases} \qquad (9)$$

Note that in order to compare $\tilde{S}_1$ and $\tilde{S}_2$, both values of $V(\tilde{S}_1 \geq \tilde{S}_2)$ and $V(\tilde{S}_2 \geq \tilde{S}_1)$ are required.

6. Assuming that $d'_i = min\{V(\tilde{S}_i \geq \tilde{S}_k)\}$, the weight vector is $w' = (d'_1, d'_2, \ldots d'_n)^T$.

7. Finally, after normalization, the normalized non-fuzzy weight vector is given by:

$$W = (d_1, d_2, \ldots, d_n)^T = (\frac{d'_1}{\sum_{i=1}^{n} d'_i}, \frac{d'_2}{\sum_{i=1}^{n} d'_i}, \ldots, \frac{d'_n}{\sum_{i=1}^{n} d'_i}) \qquad (10)$$

MATLAB modules are developed to implement the proposed scheme. The developed algorithm is capable of taking one or more decision matrices. For the case when only a single decision matrix is available, pre-defined TFNs are used to define the end-user's preferences.

Tables 2 and 3 depict the FAHP decision matrix for level-1 and level-2 criteria for the conversational traffic class, respectively. Both crisp and fuzzy values in the form of TFNs are shown to represent the importance of each network parameter. FAHP requires that all decision factors, residing at the same level of hierarchy, should not have any interdependence between each other. This is clearly not the case with level-2 criteria where the QoS parameters (delay, jitter, PLR, and throughput) are all related to each other. This interdependence between the QoS parameters can be resolved by repeating the FAHP process again and performing various comparisons between these sub-criteria. These comparisons results in a so-called interdependence matrix that is shown in Table 4. The interdependence matrix is then multiplied by the calculated weights for level-2 criteria to obtain the weights for the QoS parameters. The final calculated weight for different parameters utilized by the conversational traffic class is shown in Equation 11. The weights for the other three classes are obtained in the same fashion as depicted in Table 5.

$$W_{Conv} = \begin{bmatrix} W_{RSS} \\ W_{Qos} \times W_{QoS-Conv-D} \\ W_{Qos} \times W_{QoS-Conv-J} \\ W_{Qos} \times W_{QoS-Conv-P} \\ W_{Qos} \times W_{QoS-Conv-T} \\ W_{Velocity} \\ W_{Nw-Loading} \\ W_{Security} \\ W_{Cost} \end{bmatrix} = \begin{bmatrix} 0.2685 \\ 0.2685 \times 0.2900 \\ 0.2685 \times 0.3812 \\ 0.2685 \times 0.0785 \\ 0.2685 \times 0.2503 \\ 0.1615 \\ 0.1459 \\ 0.1209 \\ 0.0346 \end{bmatrix} = \begin{bmatrix} 0.2685 \\ 0.0779 \\ 0.1024 \\ 0.0211 \\ 0.0672 \\ 0.1615 \\ 0.1459 \\ 0.1209 \\ 0.0346 \end{bmatrix} \begin{matrix} R \\ D \\ J \\ P \\ T \\ V \\ L \\ S \\ C \end{matrix} \qquad (11)$$

III. SIMULATION ENVIRONMENT

All FAHP and VHO modules are implemented in MATLAB and evaluated using a comprehensive test-bed developed based on the concept of RUNE [9]. RUNE is a special purpose simulator to simulate wireless networks. 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 each cell for all three network types. For the propagation model, we consider the path loss, shadow fading and Rayleigh fading. For the performance evaluation, we consider a multi-user scenario where MSs join the system based on a Poisson arrival rate and the connection duration is modeled based on an exponential distribution. A mobility model is used where new MSs are distributed uniformly in the environment and the new direction and speed of each MS is updated randomly and based on a specific correlation with the previous values. Several metrics are considered to evaluate the proposed scheme and the performance of our scheme is compared against an existing algorithm that combines the RSS threshold and network load balancing. Evaluations are based on the maximum number of arrived calls (10) in each cell with multiple MSs moving randomly at the average speeds of 1, 5, and 9 m/s.

IV. PERFORMANCE EVALUATION

The FAHP weighting scheme is used in conjunction with Techniques for Order Preference by Similarity to Ideal Solution (TOPSIS) ranking algorithm. Figure 1 shows TOPSIS-FAHP preference towards WLAN for slower moving MSs. For mid and higher speed MSs, our TOPSIS-FAHP scheme correctly chooses WMAN and WWAN respectively. Other traffic classes can also be seen from Figures 1-3. The percentage of network connections preferred by TOPSIS-FAHP for different MS-speeds in depicted in Figure 4; a clear choice of network connectivity preferences at slow, medium and higher speeds can be observed and WWAN can be seen as the ABC network for MSs with higher speeds. Figure 5 shows the VHO rate utilizing TOPSIS-FAHP for conversational traffic class. An improvement of approximately 26% can be seen for MS moving at higher speed (9 m/s) with full system loading (10 calls per cell). This comparison is against the RSS-based scheme. Promising results are obtained for other traffic classes as well. Other results utilizing metrics such as handoff blocking probability, new call blocking probability and outage probability are also generated. For more details, readers may refer to [6].

V. CONCLUSIONS

A FAHP weighting scheme supporting a Vertical Handoff algorithm, was proposed. By utilizing FAHP weighting method, uncertainty and vagueness from subjective perceptions of user's preferences can be effectively represented. For the MS with a velocity of 2 m/s, TOPSIS-FAHP prefers WLAN for all types of traffic classes. When the MS is moving at 5 m/s, the preference is WMAN. The WWAN is preferred by TOPSIS-FAHP at much higher velocities. It was also observed that our VHO scheme, utilizing FAHP weighting, yields better results comparing to RSS-load balancing based algorithm. For instance, when subject to conversational traffic, it improves the overall VHO rate. Similar promising results were obtained for the other traffic classes.

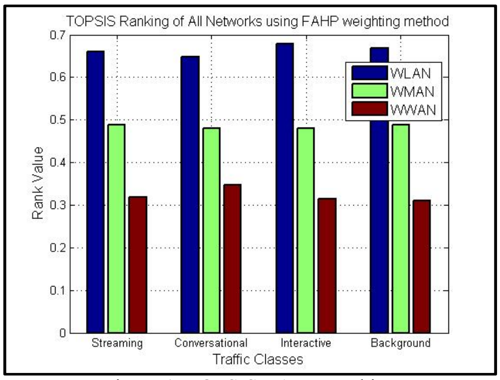

Figure 1: TOPSIS-FAHP Ranking

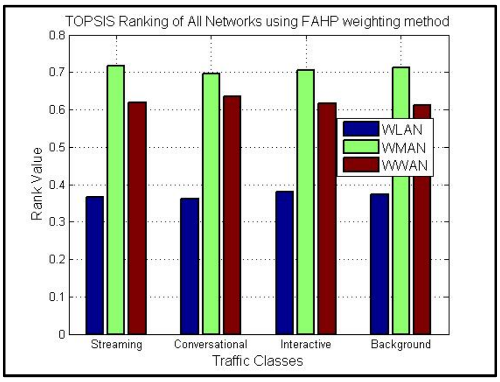

Figure 2: TOPSIS-FAHP Ranking

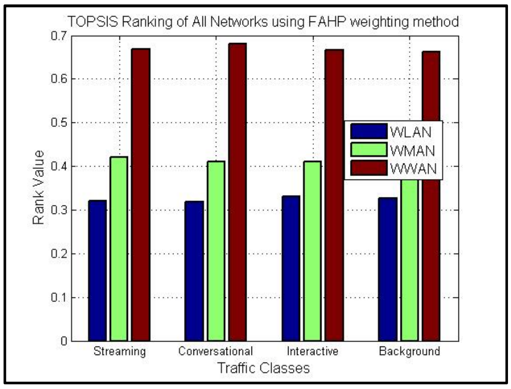

Figure 3: TOPSIS-FAHP Ranking

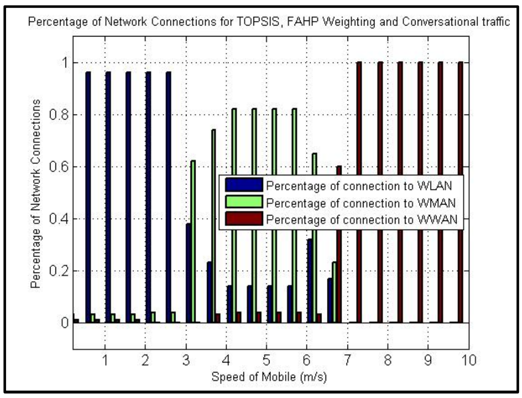

Figure 4: Percentage of Network Connection, Conversational

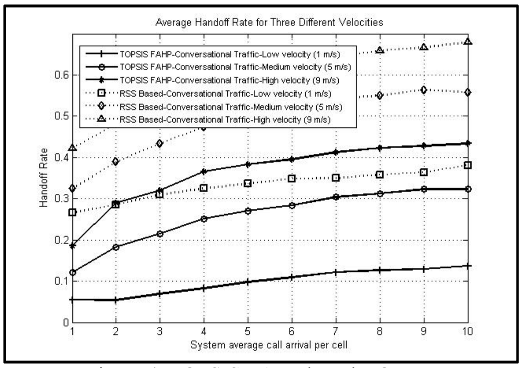

Figure 4: TOPSIS-FAHP based HO Rate

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Table 2: FAHP Decision Matrix for Leve-1 Criteria for Conversational Traffic

Criteria	RSS	QoS	Velocity	Network Loading	Security	Cost	Weights
RSS	1 (1,1,1)	1 (1,1,1)	3 (0.667,1,1.5)	4 (1,1.5,2)	5 (1.5,2,2.5)	7 (2.5,3,3.5)	0.2685
QoS	1 (1,1,1)	1 (1,1,1)	3 (0.667,1,1.5)	4 (1,1.5,2)	5 (1.5,2,2.5)	7 (2.5,3,3.5)	0.2685
Velocity	1/3 (0.667,1,1.5)	1/3 (0.667,1,1.5)	1 (1,1,1)	2 (0.5,0.75,1)	3 (0.667,1,1.5)	4 (1,1.5,2)	0.1615
Network Loading	1/4 (0.5,0.667,1)	1/4 (0.5,0.667,1)	1/2 (1,1.33,2)	1 (1,1,1)	2 (0.5,0.75,1)	4 (1,1.5,2)	0.1459
Security	1/5 (0.4,0.5,0.667)	1/5 (0.4,0.5,0.667)	1/3 (0.667,1,1.5)	1/2 (1,1.33,2)	1 (1,1,1)	3 (0.667,1,1.5)	0.1209
Cost	1/7 (0.286,0.33,0.4)	1/7 (0.286,0.33,0.4)	1/4 (0.5,0.667,1)	1/4 (0.5,0.667,1)	1/3 (0.667,1,1.5)	1 (1,1,1)	0.0346

Table 3: FAHP Decision Matrix for QoS Sub-criteria (Level-2) for Conversational Traffic

Criteria	Delay	Jitter	PLR	Throughput	Weights
Delay	1 (1,1,1)	1 (1,1,1)	3 (0.667,1,1.5)	7 (2.5,3,3.5)	0.4238
Jitter	1 (1,1,1)	1 (1,1,1)	3 (0.667,1,1.5)	5 (1.5,2,2.5)	0.3207
PLR	1/3 (0.667,1,1.5)	1/3 (0.667,1,1.5)	1 (1,1,1)	3 (0.667,1,1.5)	0.2356
T.put	1/7 (0.286,0.33,0.4)	1/5 (0.4,0.5,0.667)	1/3 (0.667,1,1.5)	1 (1,1,1)	0.0199

Table 4: FAHP Interdependence Matrix for QoS parameters

Criteria	Delay	Jitter	PLR	T.put
Delay	0.6842	0.0000	0.0000	0.0000
Jitter	0.3158	0.5000	0.3694	0.0000
PLR	0.0000	0.0000	0.3330	0.0000
T.put	0.0000	0.5000	0.2976	1.0000

Table 5: FAHP weights for all attributes based on all traffic classes

Traffic	RSS	QoS				Velocity	Loading	Security	Cost
		D	J	P	T				
Conv	0.2685	0.0779	0.1024	0.0211	0.0672	0.1615	0.1459	0.1209	0.0346
Str	0.2685	0.0325	0.0776	0.0246	0.1338	0.1615	0.1459	0.1209	0.0346
Int	0.2685	0.0588	0.0825	0.0490	0.0783	0.1615	0.1459	0.1209	0.0346
Back	0.2685	0.0444	0.0842	0.0281	0.1118	0.1615	0.1459	0.1209	0.0346