A Novel Wireless Network Access Selection Scheme for Heterogeneous Multimedia Traffic

Abolfazl Mehbodniya†, Faisal Kaleem‡, Kang K. Yen‡ and Fumiyuki Adachi†

† Tohoku University, Sendai, Japan
‡ Florida International University, Miami, FL, USA
Email: mehbod@mobile.ecei.tohoku.ac.jp {kaleemf, yenk}@fiu.edu adachi@ecei.tohoku.ac.jp

***Abstract*—Global connectivity, at anyplace and anytime, to provide high-speed, high-quality, and reliable communication channels, is now becoming a reality. The credit mainly goes to the recent technological advances in wireless communications which consist of a wide range of technologies and applications to fulfill the particular needs of end-users in different deployment scenarios (Bluetooth, Wi-Fi, WiMAX, and 3G/4G cellular systems). In such a heterogeneous wireless environment, one of the key ingredients to provide efficient ubiquitous computing, is the design of intelligent handoff algorithms, which select the optimal target network. This paper presents a novel approach for the design and implementation of a multi-criteria vertical handoff decision algorithm for heterogeneous wireless networks to achieve seamless mobility while maximizing end-users' satisfaction. After weighting the network parameters, a ranking algorithm based on the fuzzy extension of the the Techniques for Order Preference by Similarity to Ideal Solution (TOPSIS) is used to prioritize all the available networks within the coverage of the mobile user. Simulation results are provided and compared with a benchmark for a single user scenario.**

***Index Terms*—WLAN, WMAN, WWAN, Network Access Selection, Vertical Handoff, Heterogeneous Networks, FTOPSIS**

I. Introduction

Over the last few years, there have been several exciting innovations in wireless network technology [1]. The current trends and demands in wireless communication are to deliver real-time multimedia applications over heterogeneous wireless networks with guaranteed Quality of Service (QoS). The consumer demand, to access such applications and services anywhere and anytime, is continuously on the rise. New technological developments, such as the Fourth Generation (4G) wireless systems [2], offer these rich services and applications at high data transfer rates and allow global roaming and seamless mobility over a diverse range of heterogeneous wireless networks [3]. Significant research work is being done to achieve seamless mobility while a Mobile Station (MS) moves across different heterogeneous wireless networks and changes it network access using a process called, Vertical Handoff (VHO). Most of the existing VHO algorithms, which are based on single metrics such as Received Signal Strength (RSS), do not exploit the benefits of multi-criteria and the inherent knowledge about the sensitivities of these handoffs. Moreover, while performing VHOs, these algorithms do not take into account the QoS of an ongoing session to maximize end-user satisfaction based on their preferences, location and application contexts. Factors like available network bandwidth, latency, security, usage-cost, power consumption, battery status of MS, and user preferences should be thoroughly considered while performing these handoff decisions. Previous works mostly related to our research are reported in [4]–[6]. A fuzzy based adaptive handoff management protocol is proposed in [4]. Parameters like MS-velocity and distance are used by the Fuzzy Logic System (FLS) to determine the value of an adaptive RSS threshold, which is used to trigger the handoff. This work does not consider all the network attributes for the decision process. Moreover, its approach is based on RSS threshold adaptation for VHO decision, while our approach is based on multi-objective decision making. A QoS-aware fuzzy logic based multi-criteria algorithm is proposed in [5]. Analytical Hierarchy Process (AHP) is utilized to calculate the priority weights of network attributes. Only QoS-related parameters are considered to create four Fuzzy Logic Controllers (FLCs) for four different traffic types. The major issue with this scheme is that it relies on bulky rule sets (81 rules) for each FLC, which makes it inefficient to some extent. Furthermore, the absence of RSS, MS-Velocity and other important parameters indicate non-optimal VHO decisions. Another problem is with the utilization of AHP, which considers crisp values for attributes weighting that may result in an algorithm with reduced robustness especially in dynamic wireless environments. The research work in [6] uses parallel FLCs to normalize a subset of network parameters to rank the network alternatives. Similarly, no attention is given in this work to the handoff necessity estimation process and QoS parameters.

In this paper, we present an intelligent VHO algorithm, which dynamically selects the best target network for connection based on the end-user preferences, using an approach similar to [7]. In fact, different parameters of all available candidate networks are utilized to determine a new point of attachment (PoA) which can best fulfill the end-user's preferences, whether from the cost point of view or security. Our former work in [7] selects the target network using an automatic process without considering the specific preferences of the users. Here, we have completed our previous work by introducing the specific preferences of the user by means

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of manual setting which feeds to the algorithm. The target network selection module utilizes a fuzzy extension of a multi-criteria decision making algorithm called, the Techniques for Order Preference by Similarity to Ideal Solution (TOPSIS). We have chosen a fuzzy approach for a more precise modelling of the dynamic nature of wireless medium, and dealing better with the inherent uncertainty of network parameters and constraints. Our fuzzy TOPSIS (FTOPSIS) algorithm ranks all the available networks based on multiple criteria in the order of priority. Our scheme considers four different types of traffic classes, namely, conversational, background, interactive and streaming. A total of nine attributes are considered for multiple criteria decision making including a comprehensive set of network QoS-related parameters. We have examined our scheme by developing a single-user scenario simulation test-bed which simulates a wireless heterogeneous environment with three different networks, i.e., Wireless Local Area Network (WLAN), Wireless Metropolitan Area Network (WMAN) and Wireless Wide Area Network (WWAN). The performance of our scheme is evaluated and compared with a traditional TOPSIS algorithm using the percentage of user'connections to each of the aforementioned three networks as the evaluation metric.

The remainder of this paper is organized as follows. In Section II, our proposed scheme is explained. Section III presents our simulation environment along with our simulation results for a single-user scenario. Finally, concluding remarks are drawn in section IV.

II. Proposed Scheme

In the first stage of our algorithm, the attributes from all networks in range are measured and then the weights for each attribute are calculated, characterized on the specifications of each traffic class. Our scheme utilizes a few carefully chosen attributes that are critical to maximize the end-users' satisfaction while performing efficient handoffs. 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). It is assumed that these attributes are available to the MS through some mechanism; for example, GPS module installed in most MSs are capable of estimating the MS's velocity. Although schemes like [8] also consider MS's remaining battery status, it is purposely ignored in the proposed scheme as the end-user can control this attribute; for example, by connecting a battery charger while travelling. At the next stage, the future values for each network's RSS is predicted based on Grey Prediction Theory (GPT) and this predicted value is used instead, in order to improve the precision of the algorithm as well as reducing the outage probability of the system. Finally all these attribute are normalized and fed into the target network selection module for prioritization and decision on the best target network. For simplicity, we assume that the MS is equipped with multiple wireless interfaces and it can connect to different types of networks, but at a given instant of time it is connected to only one network type. The types of networks include WLAN, WMAN and WWAN. Note that here we use these three terms to present our scheme in a general manner. However, our scheme can be adapted for any technology, e.g., LTE-advanced. In the following, we explain our weight calculation technique and the target network selection module.

A. Weight Calculations for System Attributes

From a decision making perspective, the end users can specify their needs and preferences by assigning priority weights to each system attribute. Since the goal of our scheme is to maximize end-user's satisfaction, higher weights are assigned to network RSS and QoS. Furthermore, since QoS requirements vary for various types of traffic classes, different weights with respect to traffic types, need to be calculated and assigned, specifically for QoS-related parameters. The proposed scheme considers four different types of traffic classes with different characteristics and QoS demands as defined by 3GPP TS-23.107 specifications [10]. Note that the assignments and calculations of these weights can either be manual or automated using different techniques as discussed below. Our proposed scheme is flexible and offers both manual and automated weight calculations using different techniques. Two hierarchy levels of criteria are considered. The order of preference for level-1 criteria is given by: 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 attributes, i.e., network throughput, latency, jitter and PLR, is defined by our proposed scheme. Different requirements related to the QoS of the four traffic classes are taken into account as well. The detail of our weight calculation process for the four traffic classes is elaborated in [9].

B. Target Network Selection

In order to select the best target network, we first use a FTOPSIS algorithm to prioritize all the networks in range. In our approach, the weights of the attributes and the performance ratings of all available alternatives are evaluated using linguistic variables. These linguistic variables are expressed as trapezoidal or Triangular Fuzzy Numbers (TFNs). Table I shows the linguistic variables along with the corresponding TFNs. The steps of the FTOPSIS ranking algorithm are [7]:

TABLE I
Linguistic Variables and Their TFNs

Linguistic Variable	TFN
Very Low (VL)	(0.0, 0.0, 0.2)
Low (L)	(0.0, 0.2, 0.4)
Medium (M)	(0.2, 0.4, 0.6)
High (H)	(0.4, 0.6, 0.8)
Very High (VH)	(0.6, 0.8, 1.0)
Excellent (E)	(0.8, 1.0, 1.0)

1) *Formation of Committee of Decision Makers*: A committee of k decision-makers is formed where fuzzy ratings of alternatives and weights of criteria obtained from each decision maker D_k can be represented as TFN $\tilde{x} = (l,\ m,\ u)$ with the membership function given by

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

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 [12].

2) *Fuzzy Decision Matrix Construction*: This step is the same as the classical TOPSIS [11] with the exception that the ratings of all attributes are represented as TFNs instead of crisp values according to

$$\tilde{D}_k = \begin{matrix} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} \begin{matrix} C_1 & C_2 & \cdots & C_n \\ \left[\begin{matrix} \tilde{d}_{11} & \tilde{d}_{12} & \cdots & \tilde{d}_{1n} \\ \tilde{d}_{21} & \tilde{d}_{22} & \cdots & \tilde{d}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{d}_{m1} & \tilde{d}_{m2} & \cdots & \tilde{d}_{mn} \end{matrix}\right] \end{matrix} \quad (2)$$

where $\tilde{d}_{ij}$ is the fuzzy performance rating of the alternative A_i with respect to the criterion C_j, provided by the k^{th} decision maker and is expressed as a linguistic variable or TFN.

3) *Aggregation of Ratings and Weights from k Decision Makers*: The fuzzy ratings of alternatives and fuzzy weights of each attributes obtained from *k* decision makers are aggregated and are given by:

$$\tilde{D} = (d_l, d_m, d_u) \quad \tilde{W}_j = (w_{jl}, w_{jm}, w_{ju}) \quad (3)$$

where

$$d_l = \min_k \left(d_l^k\right), d_m = \frac{1}{K}\sum_{k=1}^{K} d_m^k, \\ d_u = \max_k \left(d_u^k\right) \text{ for } k = 1, 2, ..., K \quad (4)$$

and

$$w_{jl} = \min_k (w_{jl}^k)\ , w_{jm} = \frac{1}{K}\sum_{k=1}^{K} w_{jm}^k, \\ w_{ju} = \max_k (w_{ju}^k) \quad \text{for } k = 1, 2, ..., K \quad (5)$$

where $d_l,$ and d_u are the lower and upper bounds of matrix element d, respectively, represented by a TFN. The lower and upper bounds of the TFN representing the weight of the j^{th} attribute is denoted by $w_{jl},$ and w_{ju} respectively.

4) *Fuzzy Decision Matrix Normalization*: Normalization may or may not be necessary depending upon the linguistic variables and their corresponding TFNs. In most cases the fuzzy decision matrix is already normalized since the TFNs belong to the range [0, 1]. Let's assume $\tilde{r}_{ij} = (\tilde{r}_{ijl},\ \tilde{r}_{ijm}, \tilde{r}_{iju})$ to be the TFN of the normalized value of alternative *i* with respect to attribute *j*. In case the normalization is necessary, a linear scale transformation may be used as follows:

$$\begin{aligned} \tilde{r}_{ij} &= \left(\frac{\tilde{r}_{ijl}}{b_j^*}, \frac{\tilde{r}_{ijm}}{b_j^*}, \frac{\tilde{r}_{iju}}{b_j^*}\right) & b_j^* = \max_i \tilde{r}_{iju} \quad & j \in B \\ \tilde{r}_{ij} &= \left(\frac{c_j^-}{\tilde{r}_{iju}}, \frac{c_j^-}{\tilde{r}_{ijm}}, \frac{c_j^-}{\tilde{r}_{ijl}}\right) & c_j^- = \min_i \tilde{r}_{ijl} \quad & j \in C \end{aligned} \quad (6)$$

where B and C are the sets of Benefit and Cost based criteria, respectively.

5) *Weighted Normalized Decision Matrix Construction*: This matrix is constructed by multiplying each element $\tilde{r}_{ij}$ with its associated weight $\tilde{w}_j$ as:

$$\tilde{v}_{ij} = \tilde{r}_{ij}\tilde{w}_j \quad (7)$$

6) *Calculation of Fuzzy Positive & Negative Ideal Solution*: The fuzzy positive and negative ideal solutions, $\tilde{A}^+$ (FPIS) and $\tilde{A}^-$ $(FNIS)$, respectively, are defined as:

$$\tilde{A}^+ = \left(\tilde{v}_1^+,\ \tilde{v}_2^+, ...,\ \tilde{v}_n^+\right) \qquad \tilde{v}_j^+ = \max_i v_{iju} \quad (8)$$

$$\tilde{A}^- = \left(v_1^-,\ v_2^-, ...,\ v_n^-\right) \qquad \tilde{v}_j^- = \min_i v_{ijl} \quad (9)$$

where $\tilde{v}_j^+$, and $\tilde{v}_j^-$ represent the maximum and minimum ratings of the alternative with respect to the j^{th} criterion, respectively.

7) *Calculation of Separation between Alternatives & Fuzzy Ideal Solutions*: The separation (distance) between each alternative from the fuzzy positive ideal and fuzzy negative ideal solutions are calculated as follows:

$$d_i^+ = \sum_{j=1}^{n} d_v(\tilde{v}_{ij},\ \ \tilde{v}_j^+) i = 1,\ 2, ..., m \quad (10)$$

$$d_i^- = \sum_{j=1}^{n} d_v(\tilde{v}_{ij},\ \ \tilde{v}_j^-) i = 1,\ 2, ..., m \quad (11)$$

where $d_v(*, *)$ is the distance measurement between two fuzzy numbers calculated by using the vertex method as follows:

$$d_v\left(\tilde{A}, \tilde{B}\right) = \\ \sqrt{\frac{1}{3}[(a_l - b_l)^2 + (a_m - b_m)^2 + (a_u - b_u)^2]} \quad (12)$$

8) *Calculation of Relative Closeness to the Ideal Solution*: This step involves calculating the relative closeness to the fuzzy ideal solutions, which is defined as:

$$C_i = \frac{d_i^-}{d_i^- + d_i^+} \qquad i = 1, 2, ..., m \quad (13)$$

9) *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, where alternative A_i will be closer to $\tilde{A}^+$ and farther from $\tilde{A}^-$, as C_i approaches 1.

The first three steps in the original FTOPSIS algorithm collect information from multiple decision makers and create an aggregated fuzzy decision matrix for ratings and an aggregated preference weights vector for all attributes. In the network selection problem these steps don't usually fit well as the information is measured directly from the available networks and is not provided by any decision maker; the only exception to this is the weight vector, where the weights of some of the attributes such as RSS and QoS can be collected and aggregated from multiple design engineers and can be pre-assigned. As a solution to this problem, we read multiple samples of each attributes from all available networks and then create and aggregate the fuzzy decision matrix, following the steps presented for the FTOPSIS ranking algorithm. This approach helps to incorporate the fuzziness and vagueness of imprecise values of each measured attribute.

III. Performance Evaluation

In this section, we present our simulation environment along with the simulation results for a single-user scenario.

A. Simulation Environment

Our simulation program is designed based the Rudimentary Network Emulator (RUNE) [13], a special purpose simulator for wireless networks. We have used a cellular model for three co-existing wireless networks, i.e., WLANs, WMANs, and WWANs. The WLAN is defined with 27 cells with a radius of 100m each. The WMAN and WWAN are defined with 12 cells, each with a radius of 375m and 750m, 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. The network topology is shown in Fig. 1 and the numerical values for the networks' parameters are illustrated in Table II. We consider a single-user scenario similar to [7], where a mobile user travels along a predefined straight trajectory and we evaluate the percentage of time that the user is connected to each network in range. However, the objectives of this work is different than [7], as explained earlier in Section I. Here we focus on the user preferences and we investigate the behavior of our algorithm, when the user manually assigns its preferences based on security or cost optimization.

B. Simulation results

In this section, different simulation results are presented based on the end-user's preferences in terms of cost and security. Once again, we still assume the presence of only one MS moving in a straight line with access to different wireless access networks. Simulation results for only Streaming traffic class is presented here, the results for the other traffic classes can be obtained in a similar fashion. The FTOPSIS based network selection scheme is compared with a traditional TOPSIS scheme which uses an AHP process to weight the network parameters. Throughout the simulation, network parameters are kept constant according to Table II.

TABLE II
NETWORK PARAMETERS

	WLAN	WMAN	WWAN
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)	6	4	7
Cost (1-10)	2	4	7

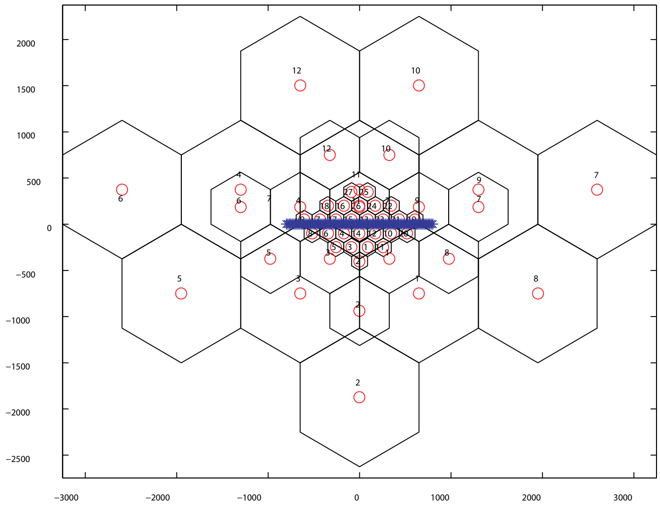

Fig. 1. Network Model.

Figs. 2 and 3 show the percentage of network connections versus velocity for the preferred user cost and streaming traffic when a traditional TOPSIS and a FTOPSIS algorithm are used, respectively. It is observed that Topsis based scheme chooses WMAN for lower and medium speeds, which is not a precise selection. However, our proposed FTOPSIS based scheme respects the users' preference of cost by assigning the MS with a slow to medium speed to WLAN. For higher MS-speed, 100% of the network connection is towards WWAN. This is because for a MS with higher mobility, our scheme prefers WWAN by taking into account all the decision variables. Even though the user wants a low cost network and WLAN can fulfill this requirement for the most part, FTOPSIS intelligently assigns a higher speed MS to WWAN to guarantee continuity and quality of the currently utilized service.

Figs. 4 and 5 show the percentage of network connections versus speed of mobility for the preferred user security and streaming traffic when a traditional TOPSIS and a FTOPSIS algorithm are used, respectively. As per the chosen network settings (refer to Table II), WWAN and then WLAN provide higher security as compared with any other network. FTOPSIS chooses WWAN for a medium to higher speed MS. For slower speed, a connectivity preference of 20% can be seen towards WWAN. The traditional TOPSIS based algorithm chooses only the WWAN throughout the mobile session. Given that the difference of WLAN and WWAN is not considerable from security point of view, our FTOPSIS based algorithm helps at load balancing and benefits from the advantages of WLAN by utilizing the WLAN in about 80% of time for lower speeds.

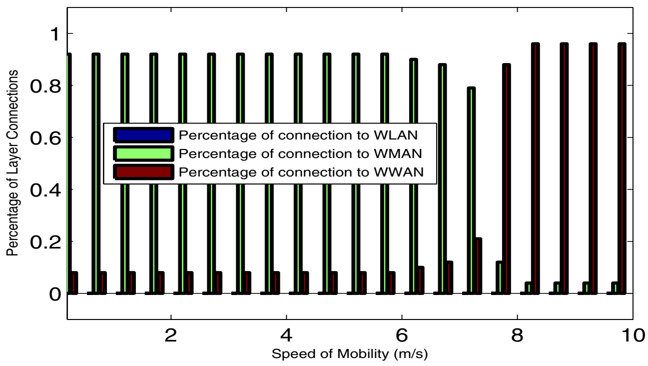

Fig. 2. Percentage of NW-Connection versus speed of mobility for Preferred Cost, TOPSIS, Streaming Traffic.

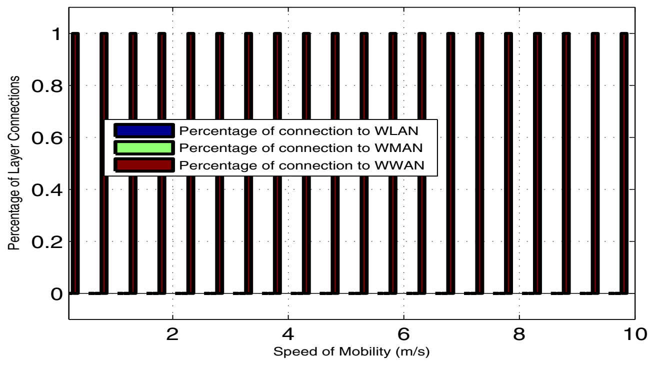

Fig. 4. Percentage of NW-Connection versus speed of mobility for Preferred Security, TOPSIS, Streaming Traffic.

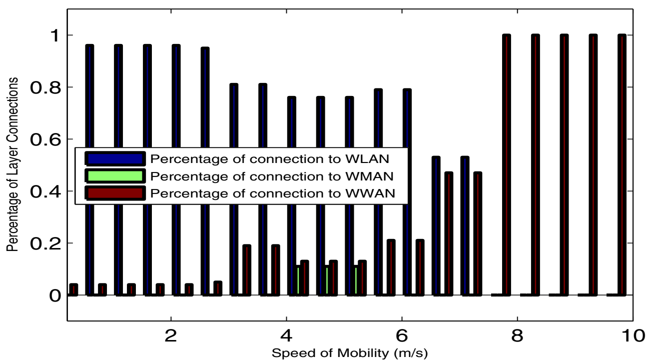

Fig. 3. Percentage of NW-Connection versus speed of mobility for Preferred Cost, FTOPSIS, Streaming Traffic.

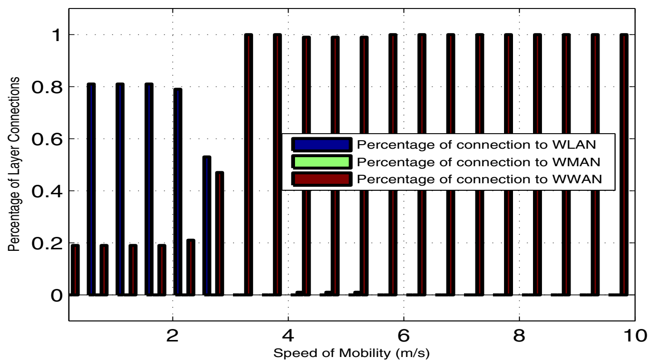

Fig. 5. Percentage of NW-Connection versus speed of mobility for Preferred Security, FTOPSIS, Streaming Traffic.

IV. Conclusions

A Vertical Handoff (VHO) algorithm was proposed which chooses the best future network for connection based by considering different network and system parameters. The algorithm Distinguishes between for different classes of traffic, i.e., conversational, streaming, background, and interactive traffic. After dynamically calculating the weights for different network and system parameters, a FTOPSIS based ranking technique prioritizes the networks in range. For a single-user scenario, it was observed that our scheme yields better results comparing to a traditional TOPSIS based scheme. It was shown that our scheme manages the network connections more efficiently when the user's cost and security are the priorities.

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