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A fuzzy extension of VIKOR for target network selection in heterogeneous wireless environments

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ABSTRACT

In a highly integrated ubiquitous wireless environment, the selection of a network that can fulfill end-users' service requests while keeping their overall satisfaction at a high level, is vital. The wrong selection can lead to undesirable conditions such as unsatisfied users, weak Quality of Service (QoS), network congestions, dropped and/or blocked calls, and wastage of valuable network resources. The selection of these networks is performed during the handoff process when a Mobile Station (MS) switches its current Point of Attachment (PoA) to a different network due to the degradation or complete loss of signal and/or deterioration of the provided QoS. Traditional schemes perform the handoff necessity estimation and trigger the network selection process based on a single metric such as Received Signal Strength (RSS). These schemes are not efficient enough, as they do not take into consideration the traffic characteristics, user preferences, network conditions and other important system metrics. This paper presents a novel multi-attribute vertical handoff algorithm for heterogeneous wireless networks which achieves seamless mobility while maximizing end-users' satisfaction. Two modules are designed to estimated the necessity of handoff and to select the target network. These modules utilize parallel Fuzzy Logic Controllers (FLCs) with reduced rule-set in combination with a network ranking algorithm developed based on Fuzzy VIKOR (FVIKOR). Simulation results are provided and compared with a benchmark.

1. Introduction

To support seamless mobility while a Mobile Station (MS) roams within a heterogeneous wireless network, Vertical Handoff (VHO) necessity estimation and decision to select a best target network are two important aspects of the overall mobility framework. The handoff necessity estimation is important in order to keep the unnecessary handoffs and their failures at a low level. On the other hand, to maximize the end-users' satisfaction level, the decision to select the best network among other available candidates plays an important role as well. VHO algorithms based on cost-function combine multiple systems' parameters to choose the target network that offers the highest overall performance. This approach is considered optimal as compared to the other traditional approaches that rely on a single system's parameters like Received Signal Strength (RSS) or available bandwidth to make handoff decisions [1]. Further optimization of the said cost-function is necessary. This can be efficiently done by applying techniques that are based on Artificial Intelligence (AI). Hence, an optimal and efficient handoff system for heterogeneous wireless networks can be developed using Rule-based Expert Systems utilizing Fuzzy Logic, Adaptive Neural Fuzzy Inference Expert Systems (ANFIS), or Neural Expert Systems. Efficient

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implementation of rule-based expert systems is possible due to their inherent parallelism and using the inference rules that can be developed by exploiting the human knowledge of the system. Previous works mostly related to our research are reported in [2–4]. The scheme developed in [2] is implemented to handle handoffs between a Universal Mobile Telecommunication System (UMTS) and Wireless Local Area Network (WLAN). This scheme employs a pre-decision unit to check for two conditions: Condition-1 is to check if the MS is connected to WLAN and if the velocity of the MS is higher than some velocity threshold. In this case, in order to prevent a connection breakdown, a handoff to UMTS is directly initiated, disregarding other decision criteria. Condition-2 is checked if the outcome of condition-1 is false. In condition-2, if the Predicted RSS (PRSS) from WLAN is greater than its threshold, or if the PRSS measured from UMTS is less than its threshold, no handoff is triggered. After the pre-decision, the fuzzy-logic based Normalized Quantitative Decision (FNQD) is applied. Performance Evaluation Values (PEVs) are generated based on the normalization of current RSS, predicted RSS, and bandwidth. These PEVs are then used to select the target network. The research shows improved performance by reducing the number of unnecessary handoffs and by minimizing the ping-pong effect. However, calculations of these PEVs are done using fixed weights, which is not practical due to the dynamic wireless network conditions and user requirements. A fuzzy based adaptive handoff management protocol is proposed in [3]. Parameters like MS-velocity and distance are used by the Fuzzy Inference System (FIS) to determine the value of adaptive RSS threshold, which is used to trigger the handoff. In [4], the author creates three separate fuzzifiers based on separate membership functions for three parameters (RSS, velocity, and network-loading) obtained from three different wireless networks (3G, WLAN, and Worldwide Interoperability for Microwave Access (WiMAX)). The objective of this scheme is to apply fuzzy logic to achieve the normalization of network parameters so that the same parameters measured from different wireless networks can be compared directly by the FIS. The output of the FIS is a numerical value that is used to rank each candidate network. This ranking is then used to determine the best access network. Neither of the aforementioned works consider Quality of Service (QoS) parameters and end-users' preferences, nor do they use all necessary system parameters for target network selection.

A wireless environment is characterized by its dynamic nature, inherent uncertainty, and imprecise parameters and constraints. Network parameters like throughput, RSS, and network delays, etc., are intrinsically imprecise. Due to this vagueness, the accurate measurement of these network parameters in a wireless environment is a difficult task. As a result, a fuzzy logic approach seems to yield better results when used for system design in such environments. So far, several Multi Attribute Decision Making (MADM) algorithms are used to establish rankings among available candidate networks. However, due to the imprecise and vague nature of the input data, they are unable to produce efficient handoff decisions; the uncertainty in user preferences (in the form of criteria weights) is considered while the impreciseness in the measured data is ignored. Hence, in this paper, a novel target network selection scheme is presented within the context of the heterogeneous wireless networks. This scheme utilizes Fuzzy VIKOR (FVIKOR): {Serbian: VIseKriterijumsa Optimizacija I Kompromisno Resenje, i.e., a multi-criteria optimization and compromise solution} ranking algorithm [5], combined with a weight elicitation technique that are implemented to select the best target network. To the best of our knowledge, this research work is the first attempt to apply FVIKOR to select a best network among other available candidate networks in a heterogeneous wireless environment. A weighting scheme is also developed based on Fuzzy Linguistic variables to deal with uncertainty and vagueness in user-provided preferences and network parameters by treating them as fuzzy data. Three networks are assumed for this research, i.e., WLAN, Wireless Metropolitan Area Network (WMAN), and Wireless Wide Area Network (WWAN). The parameters chosen from each network include PRSS, QoS-related parameters (delay, jitter, Packet Loss Ratio (PLR), and throughput), speed of the MS including its moving direction, distance between the Base Stations (BSs), traffic-loading conditions, security preferences, and the cost of the provided service. Four different types of traffic classes, namely, Conversational, Streaming, Background, and Interactive, are considered. In order to elaborate our FVIKOR-based network ranking process, we first demonstrate an exemplary scenario along with the detailed calculations of different steps of the ranking process. Moreover, in order to evaluate the overall performance of our scheme, we create a detailed VHO algorithm by integrating the ranking process which is used for the target network selection with a handoff initiation module called VHO Necessity Estimation (VHONE). Later, we examine this VHO algorithm by developing a comprehensive test-bed which simulates a wireless heterogeneous environment. Different Radio Resource Management (RRM) modules are integrated into this test-bed including, heterogeneous channel allocation, user mobility and call admission control modules. The performance of our scheme is evaluated and compared against an existing reference algorithm for two scenarios, i.e., a multi-user scenario where different users join the system randomly and a single-user scenario where one user travels along a predefined trajectory. The remainder of this paper is organized as follows. In Section 2, our proposed scheme is explained. Section 3 discusses the simulation environment along with the evaluation results based on different network performance metrics. Finally, concluding remarks are drawn in Section 4.

2. Proposed scheme

Fig. 1 shows our overall VHO algorithm which consists of two modules. In the first stage, the parameters from all networks in-range are measured and then the weights for each parameter are calculated, characterized on the specifications of each traffic class. Based on the few carefully chosen parameters, our scheme maximize the end-users' satisfaction while performing efficient

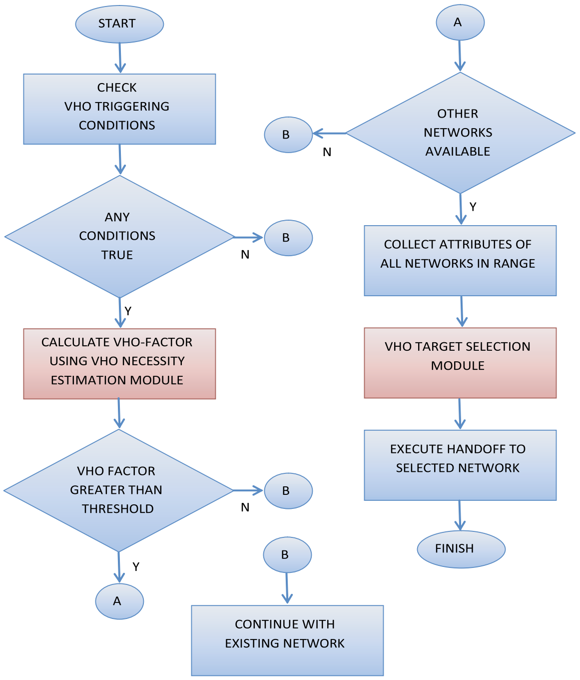


Fig. 1. Overall VHO algorithm.

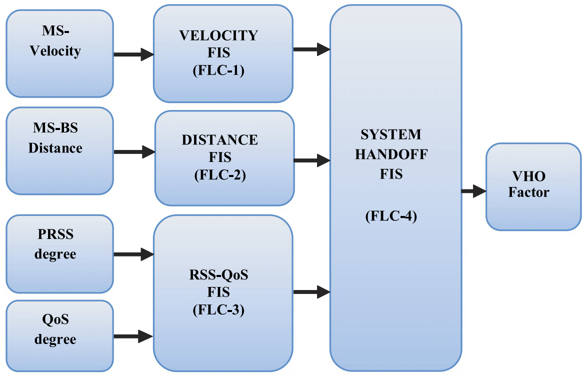


Fig. 2. VHONE module.

handoffs. It is assumed that these parameters are available to the MS through some mechanism; for example, the GPS modules installed in most MSs are capable of estimating the MS's velocity. While schemes like [6] also consider MS's remaining battery status, it is purposely ignored in the proposed scheme as the end-user can control this parameter; for example, by connecting a battery charger while traveling. At the next stage, the future values for each network's RSS are 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 parameters are normalized and fed into the VHONE module as shown in Fig. 2. The VHONE module utilizes Fuzzy Logic Controllers (FLCs) to examine the existing conditions of MS's current Point of Attachment (PoA) and calculates a handoff factor which is later compared to a certain threshold constant for decision about the handoff. Changing this threshold value is a tradeoff factor which helps us balance the system. In order to reduce the number of rules and system complexity, three FLCs are combined in a parallel fashion. The outputs of these three FLCs are then fed into the fourth FLC that produces the final VHO factor. Both Sugeno [7] and Mamdani [8] type FISs with carefully designed rules are incorporated into these FLCs. 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. If the handoff factor goes above a threshold, the algorithm enters the VHO target selection module, where the target network for the future connection is determined. With the exception of distance between the MS and the serving PoA, the same parameters as in VHONE are also utilized in the target network selection module to determine the best target network among a list of candidates. Please note that the emphasis and contribution of this work is on the Physical Layer. For cross-layer design issues of our proposed algorithm a scheme similar to [9–12] can be considered. For more details on the design of our VHONE module, the readers may refer to [13]. In the following we will explain our weight calculation technique along with the target network selection module.

2.1. Weight calculations for system parameters

From a decision making perspective, priority weights can be assigned to each system parameter to specify the needs and preferences of end-users. Higher weights are chosen for network RSS and QoS as the goal of our scheme is 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, specifically for QoS-related parameters. The different characteristics and QoS demands for these traffic classes are defined by 3GPP TS-23.107 specification [14]. Note that the assignments and calculations of these weights can either be manual or automated. Our scheme is flexible and offers both manual and automated weight calculations using different weight elicitation techniques. Two 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 is assigned by the end user whereas the relative importance for the second-level parameters, i.e., network throughput, latency, jitter and PLR, is defined by our scheme based on the 3GPP TS-23.107 specification. The detailed weight calculation for each traffic class is given in [13].

Table 1
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)

2.2. Target network selection

VIKOR is a Multi-Attribute Decision Making (MADM) method which is developed to optimize the multi-attribute based complex systems. It is a compromise programming approach that is based on an aggregating function that represents closeness to the ideal solution. The crisp-value based VIKOR [5] is able to determine a compromise ranking list of alternatives in the presence of conflicting criteria. This characteristic makes VIKOR an appropriate ranking and decision algorithm for handoff decisions in heterogeneous wireless networks. In the classical VIKOR method, the ratings of the alternatives and the weights of the criteria are known precisely and crisp values are assumed and used during the ranking process. To deal with the fuzzy nature of the wireless environment, we use FVIKOR, where the weights of the attributes and the performance ratings of all available alternatives are evaluated using linguistic variables. FVIKOR [15] is an extension to the original algorithm to include the domain of vagueness and fuzziness. The steps for the traditional FVIKOR algorithm are outlined as follows:

(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 are evaluated using linguistic variables. These linguistic variables can be proven very useful when dealing with complex problems involving uncertainty. For the case of network selection, the uncertainty resides in the vague preferences specified by the end-users. These linguistic variables are expressed as trapezoidal or Triangular Fuzzy Numbers (TFNs). Table 1 shows the linguistic variables along with the TFNs. The membership function for TFN, $\tilde{x} = (l, m, u)$ is defined by:

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

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 [16].

(2) *Fuzzy decision matrix construction*: This matrix is

$$\tilde{D}_k = \begin{array}{c c} & \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_m \end{array} & \begin{bmatrix} \tilde{d}_{11} & \tilde{d}_{12} & \cdots & \tilde{d}_{1n} \\ \tilde{d}_{21} & \tilde{d}_{22} & \cdots & \tilde{d}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{d}_{m1} & \tilde{d}_{m2} & \cdots & \tilde{d}_{mn} \end{bmatrix} \end{array} \tag{2}$$

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

(3) *Aggregation of decision makers' ratings and weights*: The aggregation of ratings and weights from k decision makers is obtained by:

$$\tilde{w}_j = \frac{1}{k}\left[\tilde{w}_j^1 + \tilde{w}_j^2 + \cdots + \tilde{w}_j^k\right] \tag{3}$$

$$\tilde{x}_{ij} = \frac{1}{k}\left[\tilde{x}_{ij}^1 + \tilde{x}_{ij}^2 + \cdots + \tilde{x}_{ij}^k\right] \tag{4}$$

where $\tilde{w}_j$ is the aggregated weight of the jth attribute and $\tilde{x}_{ij}$ is the aggregated rating of the ith alternative with respect to the jth attribute in the fuzzy decision matrix.

(4) *Determination of the Fuzzy Best and Fuzzy Worst Values*: The Fuzzy Best Value (FBV) $\tilde{f}_j^+$ and the Fuzzy Worst Value (FWV) $\tilde{f}_j^-$ for all criteria are determined by:

$$\tilde{f}_j^+ = \max_i \tilde{x}_{ij} \quad j \in \text{Benefit Criteria} \tag{5}$$

$$\tilde{f}_j^- = \min_i \tilde{x}_{ij} \quad j \in \text{Cost Criteria}. \tag{6}$$

(5) *Computation of separation measures*: The separation measure $\tilde{S}_i$ of alternative A_i from the FBV, and the separation measure $\tilde{R}_i$ from the FWV are defined by:

$$\tilde{S}_i = \sum_{j=1}^{n} w_j \frac{\tilde{f}_j^+ - \tilde{x}_{ij}}{\tilde{f}_j^+ - \tilde{f}_j^-} \tag{7}$$

$$\tilde{R}_i = \max_j \left[w_j \frac{\tilde{f}_j^+ - \tilde{x}_{ij}}{\tilde{f}_j^+ - \tilde{f}_j^-} \right]. \tag{8}$$

(6) *Computation of indices* $\tilde{S}^+$, $\tilde{S}^-$, $\tilde{R}^+$, $\tilde{R}^-$, *and* $\tilde{Q}_i$: These indices are calculated as follows:

$$\tilde{Q}_i = v\left[\frac{\tilde{S}_i - \tilde{S}_i^+}{\tilde{S}_i^- - \tilde{S}_i^+}\right] + (1-v)\left[\frac{\tilde{R}_i - \tilde{R}_i^+}{\tilde{R}_i^- - \tilde{R}_i^+}\right] \tag{9}$$

where $\tilde{S}^+ = \min_i \tilde{S}_i$ defines the index with a maximum majority rule, $\tilde{R}^+ = \min_i \tilde{R}_i$ defines the index with a minimum individual regret of opponent, $\tilde{S}^- = \max_i \tilde{S}_i$, $\tilde{R}^- = \max_i \tilde{R}_i$ and v is the weight in the strategy of the maximum group utility (or the majority of the criteria), usually having the nominal value of $v = 0.5$.

(7) *Defuzzification of TFNs*: In the original algorithm, TFNs are converted into crisp values using Shan's [17] method of maximizing set and minimizing set. In order to simplify the process, this research work utilizes the centroid method to perform defuzzification as follows:

$$\text{Crisp}_{\tilde{A}} = \frac{1}{6}\left(l_{\tilde{A}} + 4m_{\tilde{A}} + u_{\tilde{A}}\right) \tag{10}$$

where l, and u are the lower and upper bounds of Fuzzy Number A.

(8) *Ranking the alternatives*: The ranking of the alternatives is based on the crisp values of $\tilde{Q}_i$, as this index implies

the separation measure of the alternative A_i from the best alternative, i.e., an alternative with better performance as compared to others is indicated by the smaller value of $\tilde{Q}_i$.

(9) *Propose compromise solution*: The last step of the process is to propose a compromise solution A' using the crisp values of the $\tilde{Q}_i$ index if the following condition is true:

$$(Q_{A''} - Q_{A'}) \geq DQ \tag{11}$$

where $DQ = \frac{1}{M-1}$, M is the number of available alternatives, and A'' is the alternative that comes out in second position based on the minimum values of Q index.

If the condition in Eq. (11) is not satisfied, then $A', A'', \ldots, A^{(m)}$ are compromise candidates and the best alternative is the one with the minimum Q index value.

Please note that the preference weights for the parameters required by the FVIKOR ranking algorithm must be calculated using linguistic variables. Hence, the weighting method proposed in Section 2.1 should undergo an additional process, as the final weights generated by this method are crisp in nature. Therefore, two alternatives are proposed:

- The direct use of linguistic variables for all the parameters. These weights in terms of linguistic variables can be obtained from multiple decision makers that can include network operators as well as end-users. These preferences from operator and end-user can be aggregated following the first three steps of the FVIKOR ranking algorithm.
- The usage of linguistic variables for all the parameters in addition to performing a similar weight elicitation technique as proposed in Section 2.1. The benefit is twofold; the resolution of interdependence between any two parameters at the same level of hierarchy and the effective handling of intrinsic imprecision and vagueness associated with a user's preferences by using TFNs.

The FVIKOR algorithm that is implemented as part of this research can utilize both alternatives to calculate the final weights for each parameter. A separate weight elicitation module is implemented to support weight calculations based on the second alternative. Since this involves several mathematical and matrix operations on TFNs, MATLAB modules are created to support operations such as addition, subtraction, multiplication and division, matrix addition, matrix subtraction and matrix multiplication on TFNs.

3. Performance evaluation

In this section, first the numerical examples using a scenario based approach are provided in order to verify and validate the usability of different aspects of our scheme. Later, we present our simulation test-bed along with the performance evaluation of our VHO scheme in a dynamic heterogeneous wireless environment.

3.1. Numerical example

In this section, we present an exemplary scenario to show the performance of our VHO scheme, without considering any dynamic aspect of a real wireless environment. We assume that the MS is currently watching a

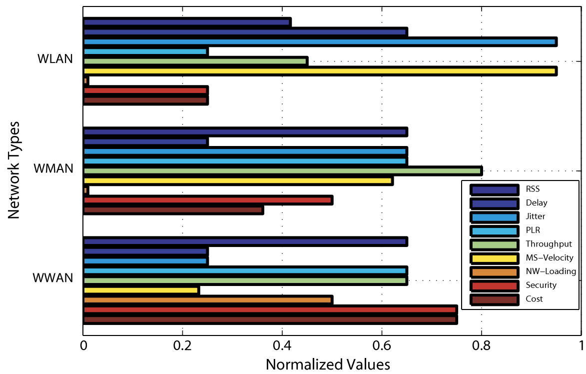


Fig. 3. Normalized networks parameters (velocity = 5 m/s).

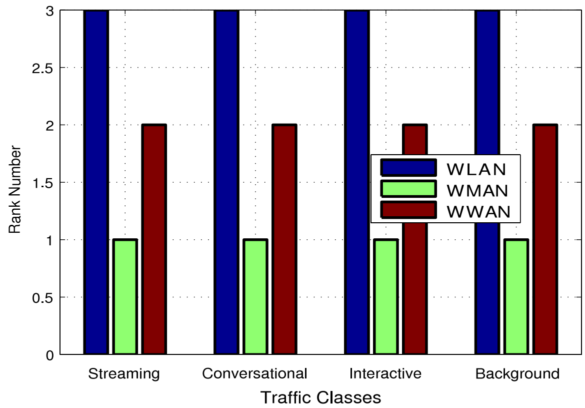


Fig. 4. FVIKOR ranking of traffic types and networks (velocity = 5 m/s).

recorded webcast (Streaming) while walking using his/her own WLAN. Later this MS steps onto a bus that starts to move with a relatively higher velocity than the walking user. Although RSS and some other parameters do not remain constant and change rapidly due to the dynamic nature of wireless networks, we will keep these values constant just to observe the effects of velocity on the network selection process. These values are fed into the target network selection module and normalized to produce their corresponding membership values based on whether the parameters are benefit or cost type. The calculations for the FVIKOR ranking scheme are shown in Tables 2–4. The parameter values for these three networks are presented in Table 5 and a graphical representation of the normalized parameter values at the MS-speed of 5 m/s is shown in Fig. 3. Fuzzy Best Values (FBV) $(\tilde{f}_j^+)$ and Fuzzy Worst Values (FWV) $(\tilde{f}_j^-)$ for Streaming traffic class are calculated and provided in Table 3. FBV and FWV for other traffic classes can be generated in a similar fashion. Table 4 shows all the numerical calculations required for the FVIKOR ranking algorithm. The triangular fuzzy number $\tilde{Q}_i$ is then defuzzified into a crisp number. The Network with the smallest value of Q_i is chosen as the target network; a smaller value implies better performance of a candidate. These network rankings are presented in Fig. 4 for all types of traffic classes. Note that only ranking number of the preferred network is displayed in this figure. Hence, the

Table 2
Weights used for different traffic classes.

Parameter	RSS	Delay	Jitter	PLR	Throughput	Velocity	Loading	Security	Cost
Streaming	E	L	M	VH	E	VH	H	M	L
Conversational	E	E	VH	M	L	VH	H	M	L
Interactive	E	VH	L	VH	M	VH	H	M	L
Background	E	L	L	M	H	VH	H	M	L
	E = Excellent, VH = Very High, H = High, M = Medium, L=Low								

Table 3
TFN representation of parameter values from three networks.

Networks	RSS	Delay	Jitter	PLR	Throughput	Velocity	Loading	Security	Cost
WLAN	[0.2, 0.4, 0.6]	[0.4, 0.6, 0.8]	[0.8, 1.0, 1.0]	[0.0, 0.2, 0.4]	[0.2, 0.4, 0.6]	[0.8, 1.0, 1.0]	[0.0, 0.2, 0.4]	[0.0, 0.2, 0.4]	[0.0, 0.2, 0.4]
WMAN	[0.4, 0.6, 0.8]	[0.0, 0.2, 0.4]	[0.4, 0.6, 0.8]	[0.4, 0.6, 0.8]	[0.6, 0.8, 1.0]	[0.0, 0.2, 0.4]	[0.0, 0.2, 0.4]	[0.2, 0.4, 0.6]	[0.2, 0.4, 0.6]
WWAN	[0.4, 0.6, 0.8]	[0.0, 0.2, 0.4]	[0.0, 0.2, 0.4]	[0.4, 0.6, 0.8]	[0.4, 0.6, 0.8]	[0.4, 0.6, 0.8]	[0.2, 0.4, 0.6]	[0.6, 0.8, 1.0]	[0.6, 0.8, 1.0]
FBV ($\widetilde{\mathbf{f}}_j^+$)	[0.4, 0.6, 0.8]	[0.0, 0.2, 0.4]	[0.0, 0.2, 0.4]	[0.0, 0.2, 0.4]	[0.6, 0.8, 1.0]	[0.0, 0.2, 0.4]	[0.0, 0.2, 0.4]	[0.6, 0.8, 1.0]	[0.0, 0.2, 0.4]
FWV ($\widetilde{\mathbf{f}}_j^-$)	[0.2, 0.4, 0.6]	[0.4, 0.6, 0.8]	[0.8, 1.0, 1.0]	[0.4, 0.6, 0.8]	[0.2, 0.4, 0.6]	[0.8, 1.0, 1.0]	[0.2, 0.4, 0.6]	[0.0, 0.2, 0.4]	[0.6, 0.8, 1.0]

Table 4
Different indices required by FVIKOR.

	Indices				WLAN			WMAN			WWAN		
	S^+	R^+	S^-	R^-	S_i	R_i	Q_i	S_i	R_i	Q_i	S_i	R_i	Q_i
Streaming	[−7.00, 1.80, 3.50]	[0.40, 0.80, 4.00]	[−1.80, 3.40, 7.90]	[0.99, 1.00, 8.00]	[−1.80, 3.40, 7.90]	[0.99, 1.00, 8.00]	[−0.40, 1.00, −2.70]	[−5.90, 1.80, 3.50]	[0.40, 0.80, 4.00]	[−0.55, 0.28, −1.59]	[−7.00, 3.10, 4.80]	[0.79, 0.80, 6.00]	[−0.56, 0.64, −2.04]
Conversational	[−6.33, 1.20, 0.78]	[0.80, 0.50, 2.40]	[−4.64, 3.91, 3.35]	[1.49, 1.00, 3.20]	[−5.66, 3.91, 3.35]	[1.49, 1.00, 3.20]	[−0.52, 1.00, −2.22]	[−4.64, 1.20, 0.79]	[1.20, 0.50, 2.40]	[−0.53, 0.12, −1.54]	[−6.33, 2.00, 0.78]	[0.80, 0.60, 2.40]	[−0.70, 0.25, −1.54]
Interactive	[−9.36, 1.40, 1.60]	[0.19, 0.80, 2.4]	[−7.10, 3.22, 4.51]	[0.99, 1.00, 4.80]	[−7.10, 3.22, 4.51]	[0.99, 1.00, 4.80]	[−0.47, 1.00, −2.43]	[−8.31, 1.40, 1.60]	[0.19, 0.80, 2.40]	[−0.60, 0.28, −1.41]	[−9.36, 2.62, 2.17]	[0.79, 0.80, 3.60]	[−0.57, 0.59, −1.87]
Background	[−3.88, 1.20, 2.75]	[0.19, 0.50, 3.2]	[−0.77, 2.91, 6.38]	[0.99, 1.00, 6.40]	[−0.77, 2.92, 6.38]	[0.99, 1.00, 6.40]	[−0.35, 1.00, −2.87]	[−2.88, 1.20, 2.75]	[0.19, 0.50, 3.20]	[−0.52, 0.13, −1.62]	[−3.88, 2.47, 3.71]	[0.79, 0.60, 4.80]	[−0.52, 0.47, −2.12]

network preferred by FVIKOR for an MS moving with a velocity of 5 m/s, is WMAN with a ranking of 1. WWAN and WLAN are second and third choices.

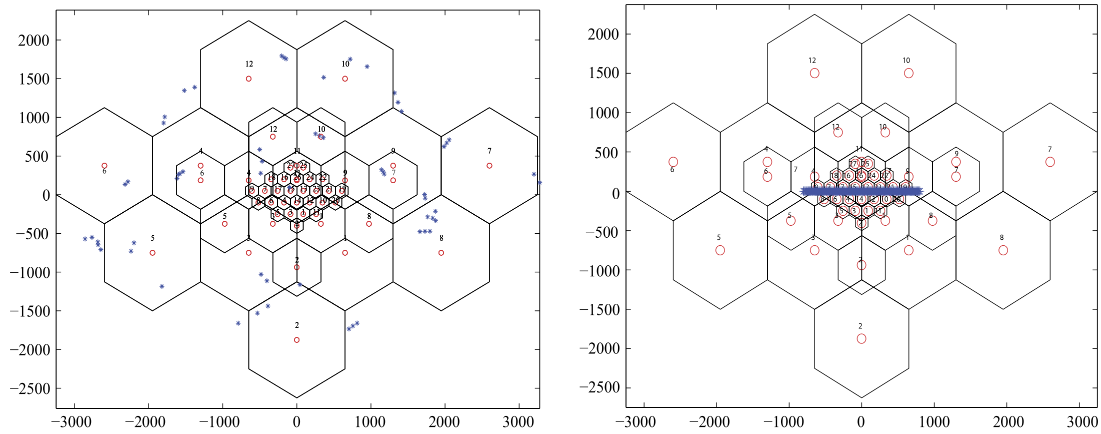
In the next sections, we will introduce a comprehensive simulation model and we will evaluate the performance of our scheme in a dynamic heterogeneous wireless environment for two scenarios, namely multi-user and single-user.

3.2. Simulation environment

The VHONE and FVIKOR target network selection modules are implemented in MATLAB and evaluated using a comprehensive test-bed developed based on the concept of Rudimentary Network Emulator (RUNE) [18], a special purpose simulator to simulate wireless networks. Several RRM modules including mobility, propagation, and traffic, are created employing a cellular concept for three co-existing networks, i.e., WLANs, WMANs, and WWANs. A number of 27 cells with a radius of 100 m each are used to define WLAN whereas, WMAN and WWAN are defined with 12 cells, each with a radius of 375 m and 750 m, respectively. The standard hexagonal shape with omni-directional antennas is considered for each cell for all three network types. A cluster of 3 cells is formed and the total frequency range for each network is divided among these 3 cells. These divided frequencies are repeated at each cluster. This arrangement is kept the same for all three network types. The total number of available channels per cell is kept as 8, 12, and 16, for WLAN, WMAN, WWAN, respectively. Channels of different networks are assumed to be orthogonal. For the propagation model, we consider the path loss, shadow fading and Rayleigh fading. Two scenarios are considered for the simulation as shown in Fig. 5, i.e., a multi-user scenario where the MSs are randomly distributed in the environment and a single-user scenario where one MS travels along a predefined path. The numerical values for the networks' parameters are illustrated in Table 6. Although the proposed scheme simulates the WLAN, WMAN, and WWAN in a general fashion, we find it necessary to provide more detail on

Table 5
Parameter set for available networks in-range (numerical example).

Parameters	WLAN	WMAN	WWAN
PRSS (dbm)	−114.05	−137.40	−116.10
Delay (ms)	130	20	10
Jitter (ms)	27	5	4
PLR (loss per 10^6 bytes)	3	4	3
Throughput (Mbps)	70	60	1.5
NW-load (%)	20	30	40
Security (1–10)	1	5	7
Cost (1–10)	3	4	7
MS-velocity (m/s)	5	5	5



(a) Multi-User Scenario. (b) Single-User Scenario.

Fig. 5. Network model.

the specific types of these networks. For instance, based on the velocity and movement range of the MSs, IEEE 802.11 a/b/g/n standards [19] can be used to implement the WLAN network. IEEE 802.16 [20], commercially known as WiMax, is a series of Wireless Broadband standards for WMAN for both fixed and mobile access. WiMax is based on Orthogonal-Frequency-Division-Multiple-Access (OFDMA) and supports frequency bands of 2–11 GHz and 10–66 GHz (licensed and unlicensed bands). In its current state, WiMax can offer a downlink speed topping 200 Mb/s. Similarly as a good candidate for WWAN, in its Release 8/9 document series, the 3rd Generation Partnership Project (3GPP) developed a standard, which is known as the Long Term Evolution (LTE) and marketed as 4G-LTE [21]. Using multiple antennas and a bandwidth of 20 MHz, LTE can offer a peak download rates up to 300 Mb/s and upload rates up to 75 Mb/s. The standard also provides improved mobility supporting terminal moving at a speed topping 300 mph.

3.3. Multi-user scenario

In the multi-user scenario multiple MSs join the system based on a Poisson arrival rate and the connection duration is modeled based on an exponential distribution. A mobility model similar to [18] is considered where new MSs are distributed uniformly in the environment and the new direction and velocity 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, i.e., average outage probability, average new call blocking probability, average handoff blocking probability and average handoff rate. We compare the performance of our scheme with an existing algorithm that combines the RSS threshold comparison 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.

The FVIKOR based network selection scheme shows a significant performance improvement over existing RSS with load balancing scheme. Figs. 6–9 depicts different evaluation metric based on Conversational traffic class and Table 7 provides these evaluations, comparing all the four traffic classes including, Conversational, Background, Streaming, and Interactive. Fig. 6 shows the average outage probability for different values of average call arrival per cell for Conversational traffic class. It is observed that for MSs moving with highest speed and at maximum number of calls per cell, the outage probability is around 40% as compared with RSS with 50%. Similarly, at medium speeds, the outage probability for FVIKOR is around 30% which shows 10% improvement over RSS.

The average handoff rate for is presented in Fig. 7. Once again, our fuzzy-data based scheme demonstrates a superior performance when compared against the reference algorithm. An improvement of about 30% can be seen for FVIKOR when compared with the RSS based scheme. These handoff rates are calculated for an average call arrival rate of 10 per cell and with MSs' speed of 9 m/s. This improvement over the existing algorithm shows that our scheme is performing handoff necessity estimation and target selection in a more intelligent and efficient manner. Fig. 8 shows the handoff blocking probability using FVIKOR as the target network selection algorithm. For MSs moving with any speed and for any number of average calls arrival per cell, FVIKOR performs better than the traditional algorithm. For the maximum number of average calls arriving per cell, the handoff blocking probability is around 75%. This can be compared against the RSS based scheme with handoff blocking probabilities of about 90%. This implies that the FVIKOR scheme makes more intelligent decisions to find the best target network which fulfills the end-user requirements. Fig. 9 shows the new call blocking probability. This figure clearly depicts an overall better performance especially for system-loading with an average call arrival rate of 2 and above. For maximum system load, FVIKOR produces a new call blocking probability of less than 70% which is better than the existing algorithm with 90% blocking at maximum load.

Table 8 shows the average percentage of connections to each of the three networks and for different MSs'

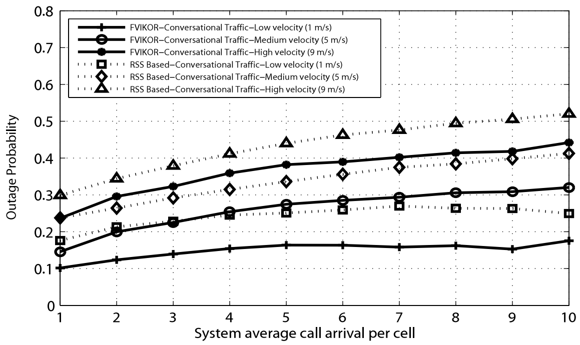


Fig. 6. Outage probability for conv. traffic using FVIKOR.

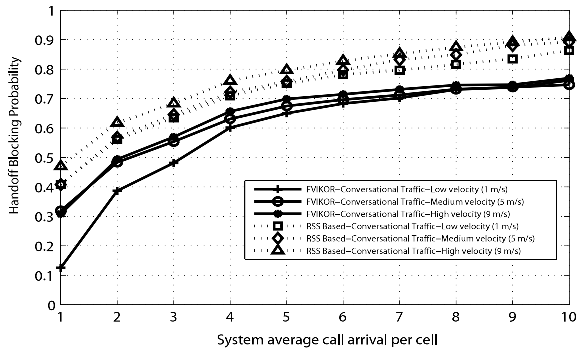


Fig. 8. Handoff blocking probability for conv. traffic using FVIKOR.

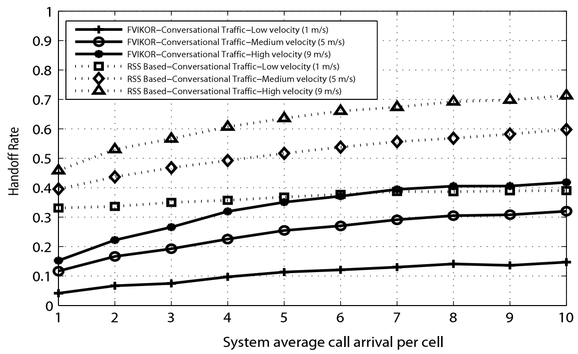


Fig. 7. Handoff rate for conv. traffic using FVIKOR.

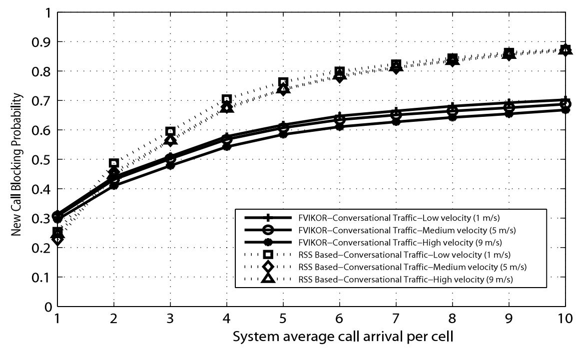


Fig. 9. Call blocking probability for conv. traffic using FVIKOR.

speeds of 1, 5 and 9 m/s for Conversational traffic class. A common trend can be observed from these figures where WWAN is consistently given higher preference as compared to WMAN, and WLAN. This is true for any mobile speed and any number of average system calls per cell. WMAN and WLAN are given second and third preferences, respectively. This is because Conversational traffic class requires a low value of delay and jitter and according to the chosen parameters listed in Table 6, WWAN provides the lowest values of these parameters, followed by WMAN and WLAN. At an average call arrival rate of 10, a distribution of connections among the three available networks can also be observed. Based on the characteristics of the Conversational traffic class, our scheme still assigns more calls to WWAN as it offers better overall QoS for the Conversational traffic class.

Table 6
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)	5	5	5
Cost (1–10)	2	4	7

3.4. Single-user scenario

In order to study the behavior of the FVIKOR network selection more precisely, we consider another scenario where a single MS travels through several networks in a predefined trajectory. During the travel time, we calculate the percentage of time that the MS has been connected to any of the three networks. Figs. 10–13 show the Percentage of Network Connections for a Single-User MS and different traffic classes. For the Background traffic class, approximately 94% and 60% connectivity preferences towards WLAN can be observed for slower and high speed mobile, respectively. At medium speed,

Table 7
Performance comparison for different traffic classes.

	Average outage prob. (%)			New call block. prob. (%)			Handoff block. prob. (%)			Average handoff rate (%)		
Speed (m/s)	1	5	9	1	5	9	1	5	9	1	5	9
Conv.	17	31	39	70	69	67	76	75	77	15	26	36
Str.	18	32	43	72	71	71	77	76	78	15	28	40
Back.	18	32	44	70	68	66	79	77	78	14	36	46
Inter.	15	27	41	71	68	66	76	76	77	15	28	41

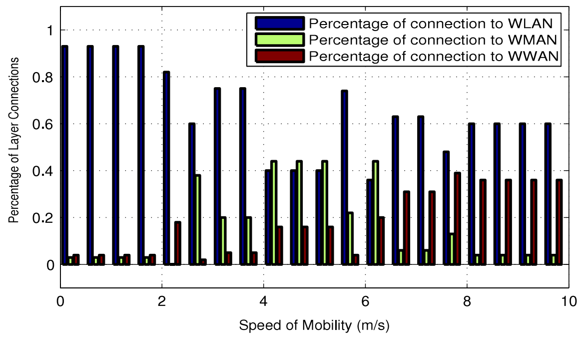


Fig. 10. FVIKOR percentage of network connection for single-user scenario, background traffic.

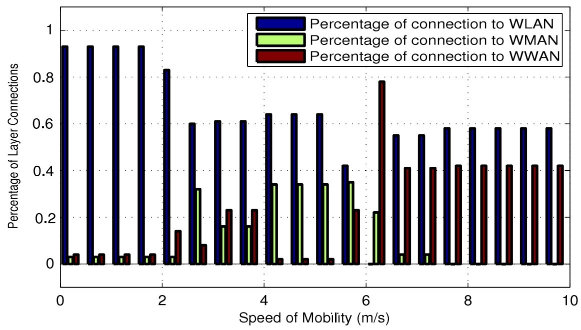


Fig. 11. FVIKOR percentage of network connection for single-user scenario, conversational traffic.

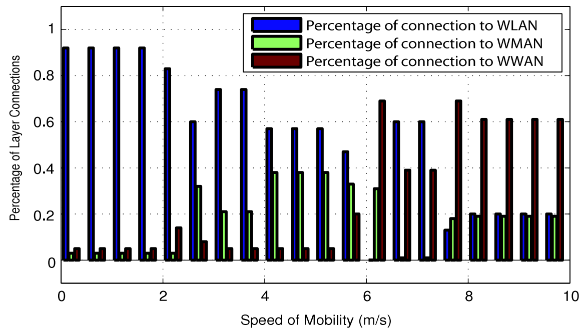


Fig. 12. FVIKOR percentage of network connection for single-user scenario, interactive traffic.

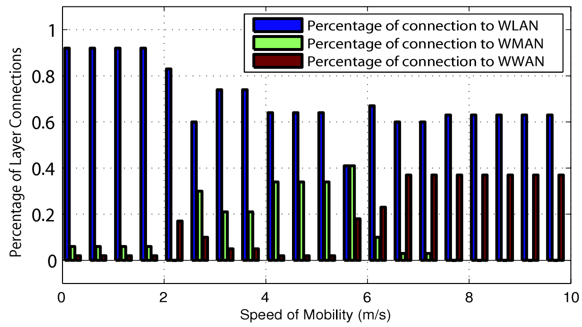


Fig. 13. FVIKOR percentage of network connection for single-user scenario, streaming traffic.

a strong competition between WLAN and WMAN can be observed from Fig. 10, where the first preference is given to WMAN with approximately 42% of network connectivity. On the higher speed side, WWAN trails WLAN with a network connectivity of 38%. An important trend that can be observed from this figure is that as the speed of the MS increases, the percentage of network connections to WLAN decreases from 94% to 60%. FVIKOR gives a higher connectivity preference for Conversational traffic class to WLAN for an MS moving with any speed. This is shown in Fig. 11. For Interactive traffic class, a mixed behavior can be observed where WLAN and WWAN are given higher connectivity preferences as compared with WMAN. This is depicted in Fig. 12. At higher speed, approximately 60% of network connections preferred WWAN. Like Conversational traffic class, FVIKOR gives similar preferences to the Streaming traffic class. The streaming traffic class requires a higher value of throughput and WLAN is the network currently providing this higher value. As can be seen from Fig. 13, WLAN is the preferred wireless network for any MS-speed whereas WMAN and WWAN are given second preferences by FVIKOR for an MS moving with medium to higher speeds, respectively.

4. Conclusions

A Target Network Selection scheme for heterogeneous wireless networks was proposed. Our Fuzzy Logic based scheme determines the best target network for future connection by taking into consideration the PRSS values of all networks in range along with their degree of the provided QoS based on the requested traffic class, the speed of the MS, networks' loading and users' cost and security preferences. Later, these values are weighted based on a fuzzy linguistic variable technique

Table 8
Network connections.

Netw.	Speed (m/s) / Call arrival	Percentage of netw. connections (%)								
	Speed (m/s)	1	1	1	5	5	5	9	9	9
	Call arrival	1	5	10	1	5	10	1	5	10
WLAN	RSS	14	22	28	10	25	29	9	26	30
WMAN		24	30	28	26	29	27	27	27	28
WWAN		62	48	44	64	46	44	64	47	42
WLAN	Conversational	10	16	24	5	12	22	6	15	23
WMAN		17	29	28	19	30	29	16	29	27
WWAN		73	55	48	76	58	49	78	56	50
WLAN	Streaming	8	17	22	6	16	20	4	14	21
WMAN		16	29	29	22	30	30	20	30	30
WWAN		76	54	49	72	54	50	76	56	49
WLAN	Background	7	9	18	5	15	24	4	16	24
WMAN		18	33	31	19	31	28	21	31	28
WWAN		75	58	51	76	54	48	75	53	48
WLAN	Interactive	7	11	16	4	13	23	4	14	22
WMAN		19	31	32	18	31	29	19	30	28
WWAN		74	58	52	78	56	48	77	56	50

and the best target network is selected using a FVIKOR ranking algorithm. It was observed that our scheme yields better results compared to the RSS-load balancing based algorithm. For instance, when subject to Conversational traffic, it improves the overall network outage probability by about 8% for average mobility (5 m/s) and average call arrival rate of (5 call/cell). Similar promising results were obtained for the other traffic classes.

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