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Radio Access Technology Selection in Heterogeneous Wireless Networks Using a Hybrid Fuzzy-Biogeography Based Optimization Technique

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Abstract Radio access technology (RAT) selection in heterogeneous wireless networks is a challenging task to achieve guaranteed quality of service (QoS). This paper proposes a hybrid methodology in order to accomplish QoS through high service connectivity and reliable network transparency in a wireless heterogeneous system. The proposed hybrid methodology integrates a non-homogenous biogeography based optimization (NHBBO) with a parallel fuzzy system (PFS). The PFSs are employed to determine the probability of RAT selection, which acts as an input to the NHBBO procedure. Thus the NHBBO decide over the defined multi-point decision making algorithm to select the best RAT in the given heterogeneous network. The key role of the proposed technique is to optimize the weight coefficients of multi-point decision making algorithm and ensure maximum user satisfaction ratio to select best RAT. Several experiments are carried out using the proposed NHBBO–PFS technique to demonstrate the effectiveness and robustness in producing solutions compared to a few existing methods for RAT selection in heterogeneous wireless networks.

Keywords Radio access technology (RAT) · Parallel fuzzy systems (PFSs) · Heterogeneous wireless networks · Non-homogenous biogeography based optimization (NHBBO)

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1 Introduction

In the current scenario, there is an extensive growth in the area of wireless mobile network systems. Fundamentally, the respective users of a wireless network have to be designated with the required number of radio resource units to communicate with the user to network links and from network to user links. The process of assigning required number of radio resource units to respective wireless networks is termed as multiple access technique. The tremendous utility of wireless modes has transformed the mobile communications from first generation to third generation to maintain the services rendered and guarantee on quality of service (QoS). Forthcoming modes of wireless communication will be based on radio access technology (RAT) selection and offered for the increasing heterogeneous systems. This paper proposes an approach with parallel fuzzy systems (PFSs) and a modified optimization algorithm; non-homogenous biogeography based optimization (NHBBO) for carrying out best RAT selection with the specified constraints being met as given by the multi-point decision making algorithm. Existing literatures with the necessary algorithms adopted for performing RAT selection in heterogeneous wireless networks are presented in detail below.

Al Sabbagh et al. [1] proposed intelligent hybrid power efficient (battery power saver) RAT selection algorithm which includes sorting available RATs, collecting information on each RAT using the IEEE P1900.4 Protocol, and making decisions for choosing the most appropriate RAT for incoming calls. Gharsellaoui et al. [2] performed a radio access network (RAN) selection novel algorithm framed for decision-making under service parameters, QoS, and service costs for the mobile user in next generation of wireless networks, the presented algorithm uses mobile terminal measurements from various radio access technologies to get information for multi-criteria decision making between various RANs available to the mobile user.

Lahby et al. [3] carried out a work on optimal network selection algorithm that allows mobile users to select the BAN with seamless manner. Moety et al. [4] suggested four distributed heuristic algorithms for RAT selection in wireless heterogeneous networks to improve global performance, where two schemes are based on the distance between the user and the access points (APs), such as, distance based and probabilistic distance based algorithms.

Pacheco-Paramo et al. [5] presented joint schemes for admission control and access technology selection with vertical handoffs improve their capacity of radio resources in heterogeneous networks. Aryafar et al. [6] performed two general classes of throughput models that capture the basic properties of scheduled access (e.g., WiMAX, LTE, 3G) and random access (e.g., Wi-Fi) networks, then frame the problem as a non-cooperative game, and study its efficiency, convergence and practicality. Carvalho et al. [7] suggested optimal JCAC for inter-RAT cell re-selection problem also considered to as initial RAT selection in co-located wireless networks, which supports both non-real-time services and real-time services.

Carvalho et al. [8] carried out a work on optimal joint-call admission control (JCAC)-based method for initial RAT selection for heterogeneous wireless networks (HetNets) composed of two co-located wireless networks supporting two different service classes. El Helou et al. [9] suggested a hybrid approach for RAT selection in heterogeneous wireless networks. Helou et al. [10] analyzed the access technology selection—a key CRRM functionality—and formulate hybrid decision framework to dynamically integrate user preferences and operator objectives.

Tseng et al. [11] performed stochastic learning-based algorithm for network selection in cognitive heterogeneous networks, each and every SU's strategy progressively evolves toward the Nash equilibrium (NE) based on its own action-reward history, without the need to know actions in other SUs. Wong et al. [12] carried out a work on a mechanism to make appropriate RAT access recommendations to user devices by the means Support Vector Machine tool. Yassin et al. [13] carried out a work on a hybrid approach that combines the distributed one with periodic centralized interventions for RAT selection in wireless heterogeneous networks.

Aymen et al. [14] presented approach for RAT selection algorithm based on fuzzy logic and includes different criteria, assessing and making decisions, then choosing the most appropriate technology. El Helou et al. [15] proposed hybrid decision framework that integrates user preferences and operator objectives, tackle the RAT selection. Kosmides et al. [16] carried out a work on the Network Selection problem to allocate terminals to the most suitable RATs by jointly examining both users' and providers' preferences. Al Sabbagh et al. [17] suggested intelligent hybrid mobility optimization and minimum cost RAT selection approach for heterogeneous wireless networks which aims to increase users' satisfaction by allocation users for cheapest cost service and connections to a RAT.

From the above literature study carried out on RAT selection for heterogeneous wireless networks, it is observed that the occurrence of unbalanced load conditions, average time delay, stability of the wireless network, service cost, user satisfaction level, utilization of radio resources has to be further addressed in order to obtain higher user satisfaction rate with better QoS guarantee, wide coverage and uniform load distribution. As a result, to achieve higher user satisfaction rate with a satisfactory level of QoS guarantee with uniform load distribution, the proposed contribution based on PFS and NHBBO is developed. Hybrid NHBBO–PFS is proposed to select best RAT in heterogeneous networks based on the multi-points formulated enabling to render higher user satisfaction rate and this facilitates to control access network selection. The effectiveness of the proposed approach is compared with that of the earlier methodologies available in the literature to prove its validity.

2 RAT Selection in Heterogeneous Wireless Networks [5]

This section presents an overview on the fundamentals of heterogeneous wireless networks adopting RAT selection mechanism and the parameters to be considered for selecting the best RAT.

2.1 Heterogeneous Wireless Networks

Heterogeneous form of wireless networks consists of various radio access technologies like Wireless Local Area Network (WLAN), Wireless Metropolitan Area Network (WMAN), Wireless Wide Area Network (WWAN), Global System for Mobile communication (GSM) and satellite networks. A mobile user in this heterogeneous mode with overlapping RAN coverage should ensure the user gets connected to the best network available based on the current needs. The entire process being multi-technology, multi-user and multi-process applications, it is required to have some new approaches for automatic network selection. With the growing developments, these networks are designed to provide video-audio processing, voice processing, web browsing, image capturing applications and so on. It is to be noted that the respective user in a considered heterogeneous wireless network will be able to access the network services only with the help of available RATs. Figure 1 shows a model of a heterogeneous wireless network.

From Fig. 1, it is viewed that the shown heterogeneous wireless network possesses two types of RAT–WLAN for local coverage logs and WWAN for global coverage logs. The coverage area logs of WLAN and WWAN are termed as micro cell and macro cell respectively. Based on the requirement of the end-users, the topology selection can be made to select the best RAT for the given heterogeneous wireless network. The operation in a heterogeneous network takes place in two steps—first, the initial step for RAT selection and second, inter-system dependencies or the handover algorithm process. As and when a new call is received in a multi-access RAT environment, the first step ensures the responsibility of selecting the most suitable RAT and the second step starts its run at the session initialization viz., vertical handover. This is the general procedure adopted to switch from one RAN to the other. In this paper, RAN is designed as a mobile access network that is built on a single RAT.

2.2 RAT Selection Parameters

RAT selection parameters [5] are based on the following four metrics—QoS guarantee, User satisfaction rate, preference of the operator, RAT availability condition. The selection for RAT may be based on any of these individual metrics or with that of the combination of all the four metrics. In respect of QoS guarantee the parameters that play a major role for RAT selection involves average delay, delay-jitter, data rate and throughput. On considering the case of User satisfaction rate the parameters for RAT selection involves low battery consumption, minimal service cost and most importantly on high network security with speed of the mobile terminal. With respect to operator preference, the parameter to be considered includes—maximizing the revenue, uniform load distribution, optimal radio

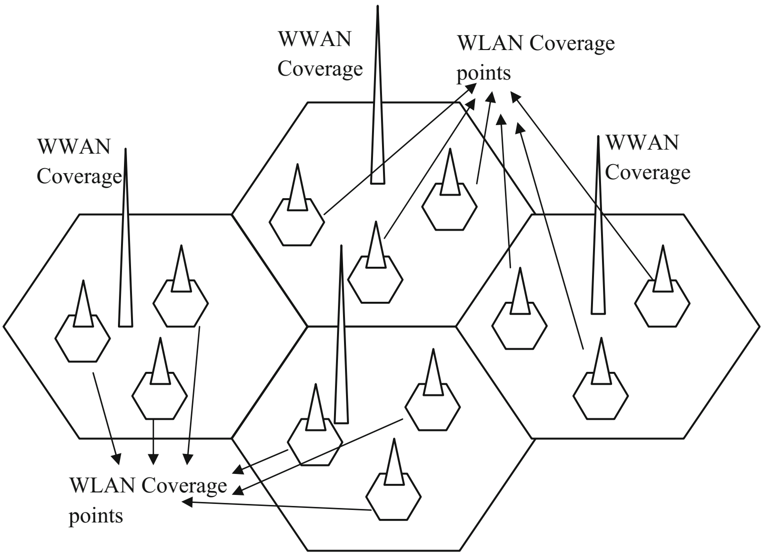

Fig. 1 A model of heterogeneous wireless network

resource utilization and minimizing the call blocking or dropping process. Most importantly on RAT condition, the significant parameters include network coverage and received signal strength.

In this paper, a combined multi-point parameter based RAT selection is carried out using the above four metrics. In a manner, to design a simple but an accurate process for RAT selection out of the 14 parameters from the given 4 metrics, the prominently used parameters [5]—Speed of the mobile terminal, Received Signal Strength, Network Coverage, Delay and Data rate of QoS are selected to carry out the process. Thus, this paper uses these five parameters as the input signals for the proposed algorithm. These five parameters form the basis for multi-point decision making algorithm. The chosen RAT selection parameters are detailed as given below:

Speed of the Mobile Terminal This references to the speed with which the operation is carried out in the terminal end. For best RAT to be selected, the speed of the mobile terminal is to be analyzed.

Received Signal Strength This is indicated by received signal strength indicator (RSSI) value. This gives the value of the power present in a received radio signal. RSSI gives the power level that is received by the antenna. Generally, this RSSI is not known for the user of the device possessing the receiver.

Network Coverage Network connectivity means to the particular RAT with the widest coverage with reduced vertical handover. Network coverage will be measured in kilometers or meters.

Delay This falls under QoS guarantee. To assure QoS guarantee, RAT which offers minimum delay for a particular service is to be chosen. Delay is a time constraint and is measured in seconds.

Data Rate In general, a user will prefer a RAT with highest data rate for reducing the delivery time of the service as well to achieve QoS guarantee. This parameter is given in kbps (kilo bytes per second) or mbps (mega bytes per second).

With the above considered parameters for the given metrics, the key objective in this paper is to maximize the user satisfaction rate with the best RAT selected among the heterogeneous networks allocated to the networks with highest received signal strength. Better results mean achieving better user satisfaction rate considering the combined parameters of speed, received signal strength, data rate, delay and network coverage. The main aspect in this case of multi-point decision making algorithm is to find suitable weights for each of these parametric constraints. This paper aims at maximizing the user satisfaction rate and determining suitable weights for each of the five parameters considered formulates the research problem.

3 Proposed Approach for RAT Selection in Heterogeneous Wireless Networks

This section details on the proposed methodology developed for RAT selection in heterogeneous wireless networks. The proposed methodology employs PFSs and NHBBO for selecting the best RAT maximizing the user satisfaction rate. The key steps involved in the proposed approach is as follows: The five input parameters speed of the mobile terminal, received signal strength, network coverage, delay and data rate are employed for selecting the better access networks. These input parameters are fed as input signals to PFSs. The outputs received from the PFSs are applied with that of the NHBBO, which is used to optimize the weight coefficients in multi-point decision making algorithm for selecting the best RANs. PFSs are employed rather than conventional fuzzy systems to reduce the complexity of inference rules. The three major procedures in proposed methodology are:

1. Design of a PFS for the given input signals
2. Formulating a Multi-point decision making algorithm with the metrics considered.
3. Optimizing weight coefficients using proposed NHBBO to determine the best RAT.

Figure 2 shows the block diagram of the proposed methodology that uses hybrid PFS–NHBBO for selecting best RAT in heterogeneous wireless networks.

3.1 Design of Proposed Parallel Fuzzy Systems

Parallel fuzzy systems is designed for a heterogeneous wireless network model with two RATs, an IEEE 802.11g based WLAN and WCDMA (Wireless Code Division Multiple Access) based WWAN as shown in Fig. 2. Each of the Fuzzy Systems for the considered 5 parameters results in a value related to the probability of selection of RAN considered in the heterogeneous system. For each of the fuzzy system, Mamdani Fuzzy Inference System [18] is adopted and mean of maximum method is used for carrying out defuzzification process. The membership functions employed for the input and output variables include triangular membership functions. Triangular membership function is used for both starting and ending regions of fuzzy variables (input and output) as well for the in-between regions of fuzzy variables (input and output). The following subsection discusses on the developed membership functions and fuzzy inference rules for the designed PFS.

3.1.1 Membership Functions for Parallel Fuzzy Systems

The first step in designing the proposed PFSs involves the formation of membership functions for the input and output variables which are the speed of the terminal, signal

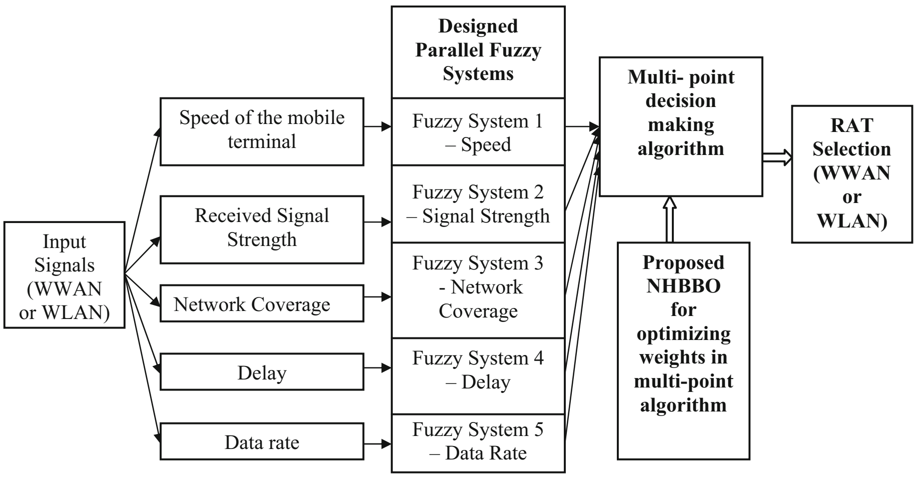

Fig. 2 Block diagram of proposed methodology for RAT selection using hybrid PFS–NHBBO

Table 1 Parameter specifications for WWAN and WLAN [20, 21]

Parameters	WWAN specification	WLAN specification
Speed (km/h)	[0 … 10]	[0 … 10]
Signal strength	[−105 … −70]	[−105 … −50]
Network coverage (m)	[0 … 10]	[0 … 10]
Delay (ms)	[0 … 1000]	[0 … 1000]
Data rate (kb/s)	[0 … 400]	[0 … 400]

strength, network coverage, delay and data rate. Table 1 specifies the range of the parameters considered for WWAN and WLAN to design PFS.

For all the five fuzzy systems designed in parallel mode, the fuzzy linguistics for input variables are—Low, Medium and High and the fuzzy linguistics for output variables are—accept (A), probably accept (PA), not accept (NA), probably not accept (PNA). Table 2 provides the list of input and output fuzzy variables for the five parameters of PFS which decides the best RAT selection.

From Tables 1 and 2, with the knowledge of the variables and their respective range specified membership functions are formulated using Mamdani fuzzy inference system [18]. Figures 3 and 4 show the membership functions for the sample fuzzy variables.

Using the membership functions as derived in Figs. 3 and 4, the process of fuzzification (converting the real values into fuzzy values) is completed in Mamdani fuzzy inference systems. Based on the membership values formulated, fuzzy inference rules are derived to compute the solution of the PFS.

3.1.2 Fuzzy Rules for Each of the Fuzzy System in Proposed PFS [18]

The next step is to derive the output from the PFSs designed for the taken five parameters. For each of the parameters based on their input and output variable, 3 linguistics (low, medium and high) are assumed for input variable and four linguistics (A, PA, NA, PNA) for output variable. Based on the fuzzy linguistics for the variables of respective parameters, the fuzzy rules are to be formed. The process of forming fuzzy rules with the formulated membership values results in fuzzy associative memory (FAM) table. The fuzzy rules are generally in the form of "If … Then" rule statements. For the considered problem, 3^4 rules can be formulated. But considering the output linguistics, the probability of occurrence for the linguistic "probably not accept" is very minimal and in the process of

Table 2 List of input and output variables of the PFS

Parameters	WWAN variables		WLAN variables	
	Input variable	Output variable	Input variable	Output variable
Speed of the mobile terminal	N	NO_1	N	NO_2
Received signal strength	SS_1	SSO_1	SS_2	SSO_2
Network coverage	NC	NCO_1	NC	NCO_2
Delay (QoS constraint)	δ	QoS_1	δ	QoS_2
Data rate (QoS constraint)	β		β	

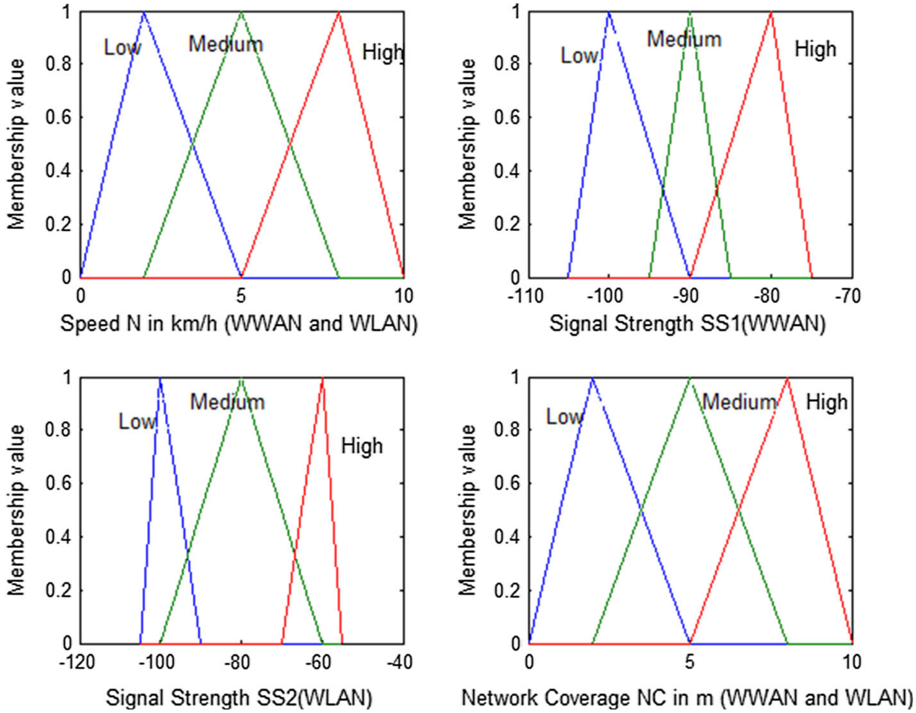

Fig. 3 Membership function of parameters—speed, signal strength and network coverage of WWAN and WLAN

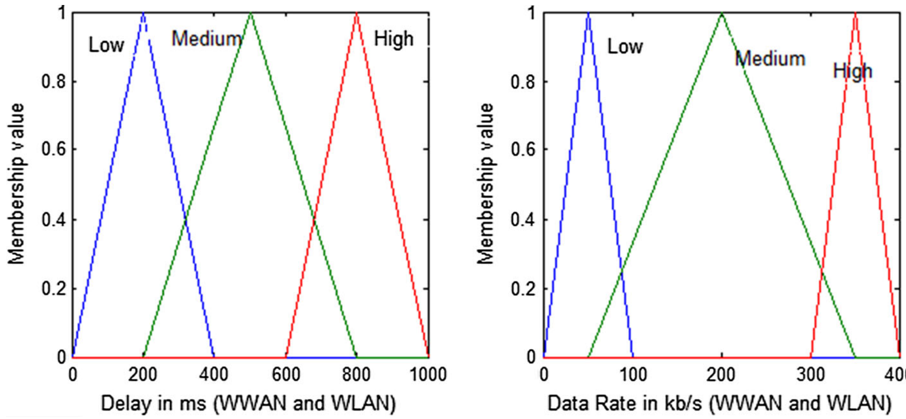

Fig. 4 Membership function of QoS parameters—delay and data rate of WWAN and WLAN

formulation of rules, the occurrence of this possibility will be negligible. As a result, trial and error operation is carried out and the optimal numbers of rules are formulated to derive the output from the proposed PFSs. Table 3a–d shows the fuzzy rules formulated for each of the proposed PFSs.

Table 3 FAM table for optimal fuzzy rules of (a) speed of the mobile terminal, (b) received signal strength, (c) network coverage, (d) QoS guarantee

N (speed)	NO_1 (WWAN)	NO_2 (WLAN)
(a)		
Low	NA	A
Medium	PA	PA
High	A	NA

SS_1	SS_2		
	Low	Medium	High
(b)			
SSO_1 (WWAN)			
Low	NA	NA	PA
Medium	PA	PA	PA
High	A	A	A
SSO_2 (WLAN)			
Low	NA	PA	A
Medium	NA	PA	A
High	PA	PA	A

NC (WWAN)	NC (WLAN)		
	Low	Medium	High
(c)			
NCO_1 (WWAN)			
Low	NA	NA	NA
Medium	PA	PA	PA
High	A	A	A
NCO_2 (WLAN)			
Low	NA	PA	A
Medium	NA	PA	A
High	A	PA	A

δ (delay)	β (data rate)		
	Low	Medium	High
(d)			
QoS_2 (WLAN)			
Low	NA	PNA	PA
Medium	PNA	PA	A
High	PNA	PA	A
QoS_1 (WWAN)			
Low	NA	PNA	PNA
Medium	PNA	PA	PA
High	PA	A	A

Based on the FAM table [25] of the parameters in Table 3, the inference obtained on evaluating the rules are detailed as follows. From Table 3a, when the speed (N) of the mobile terminal is high, then the probability of selection of WWAN (NO_1) will be higher. Also, when the speed (N) of the mobile terminal is low, then the probability of selection of WLAN (NO_2) will be higher. In Table 3b, when the signal strength (SS_1) of WWAN is higher, then the probability of selection of WWAN (SSO_1) is higher and as well when the signal strength (SS_2) of WLAN is higher, then the probability of selection of WLAN (SSO_2) is higher. From Table 3c, it is inferred that by increasing the network coverage of WWAN (NC), the probability of selection of WWAN (NCO1) is higher and it is observed that by increasing the network coverage of WLAN (NC), the probability of selection of WLAN (NCO2) is higher. It is noted from Table 3d that by decreasing the value of delay (δ) or by decreasing the value of data rate (β), the probability of selection of WLAN (QoS2) will be higher. The same applies when both variables decrease simultaneously. It is also noted from Table 3d that by increasing the value of delay (δ) or by increasing the value of data rate (β), the probability of selection of WWAN (QoS1) will be larger. The same applies if both the variables increase simultaneously. This procedure completes the proposed design of PFSs for RAT selection.

3.2 Proposed Multi-point Decision Making Algorithm and Fitness Function Formulation

In this section, the details of the multi-point parameter algorithm developed for the selection of best RAT is explained. From Fig. 2, it can be observed that the outputs of the PFSs are given as input to the multi-point parameter algorithms which contains 'weight function'. If a conventional single fuzzy system is designed for the selection of RAT, then there occurs the question on guarantee of accuracy because of the time taken to evaluate the rules. The multi-point decision making algorithm is implemented when different metrics and parameters are available. These type of problems involves evaluating the set of parameters in the considered metrics based on a particular set of decision criterion. Computing numerical measures for these parameters is a key issue in this type of multi-point decision making algorithms.

For best RAT selection in a heterogeneous network, multi-point represents the various dimensions from which the RAT selection can be viewed. Each of the objectives in the multi-point decision making algorithm is to be assigned with suitable weights such that the best RAT is selected. With this fundamental idea, the weight function of the proposed multi-point decision making algorithm has the outputs of the proposed PFS and respective weight coefficients. The outputs from the proposed PFS are NO_1, NO_2, SSO_1, SSO_2, NCO_1, NCO_2, QoS_1 and QoS_2 for WWAN and WLAN. The evaluation of these output variables are carried out along with weight function. In general, the weight function of the proposed multi-point decision making algorithm is defined as,

$$W_k = \sum_{i=1}^{n} \frac{w_i o_{ik}}{n}, \quad k = 1, 2, \ldots, m \tag{1}$$

where, W_k—ranking value for each RAT k in a heterogeneous wireless network, w_i—weight coefficients for each input option, o_{ik}—individual output values from PFSs for that many number of RATs and n—total number of input parameters.

The ranking of the two considered RATs–WWAN and WLAN in this paper are given by,

$$W_{wwan} = \frac{(w_1 \times NO_1) + (w_2 \times SSO_1) + (w_3 \times NCO_1) + (w_4 \times QoS_1)}{n} \quad (2)$$

$$W_{wlan} = \frac{(w_1 \times NO_2) + (w_2 \times SSO_2) + (w_3 \times NCO_2) + (w_4 \times QoS_2)}{n} \quad (3)$$

In the above equations, w_1, w_2, w_3 and w_4 are the assigned weight factors for speed of the mobile terminal, signal strength, network coverage and QoS respectively. The weighting factors are generally positive numbers in the range of [0, 1]. When a parameter is assigned with a highest weight, it is assumed to be a highest important objective. The maximum value of weighting factor is 1 and the minimum value of weighting factor is 0.1. On designing the multi-point decision algorithm, it is necessary to consider all the input parameters. The NHBBO algorithm is proposed over the multi-point decision algorithm in order to optimize the weight coefficients that select the best RAT in a heterogeneous wireless network.

3.2.1 Fitness Function Formulation

The main aim of RAT network selection is to maximize the users percentage assigned to the networks possessing high signal strength. Hence, while formulating the fitness function which forms the core for the proposed NHBBO, the received signal strength of the network is considered as the vital parameter. Equations (2) and (3) gives the weight function of WWAN and WLAN network respectively. The fitness function is formulated as the ratio of weight function of WLAN to weight function of WWAN. On evaluation when this value becomes greater than 1, then automatically the number of satisfied users is increased by one. Mathematically the fitness function is given by,

$$F = \frac{W_{wlan}}{W_{wwan}} \quad (4)$$

Equation (4) is the fitness function employed in the proposed algorithm to determine the selection of best RANs between WWAN and WLAN.

3.3 Proposed Non-homogenous Biogeography Based Optimization

This section presents the proposed NHBBO algorithm based on the conventional BBO algorithm. In this paper, the proposed NHBBO algorithm is applied over the multi-point decision making module to optimize the weight coefficients, so that the best WWAN and WLAN is selected. The optimal values of weight factors computed using the proposed NHBBO algorithm plays a vital role in evaluating the Eqs. (2) and (3), so that the algorithm searches to find the best RAT. Conventional biogeography based optimization (BBO) [22] consists of major two steps—migration and mutation. In the proposed Non-Homogenous BBO, a new mutation mechanism called as Non-Homogenous mutation is employed to increase the exploration capability in the search space. The details on the conventional BBO algorithm can be had from [22]. The following subsection details on the proposed NHBBO algorithm to optimize the weight coefficients for selecting best RAT in heterogeneous networks.

3.3.1 Proposed Non-homogenous Mutation Operation

Traditional BBO performs mutation operation for habitat search process. Basically, mutation is a varying operator that randomly changes the values at one or more search positions of the selected species. In Non-homogenous mutation, for each species $X_i^t = \{x_1, x_2, \ldots, x_m\}$ in the population of tth iteration, a habitat $X_i^{t+1} = \{x_1', x_2', \ldots, x_m\}$ is produced as below:

$$x_k' = \begin{cases} x_k + \Delta(t, IM - x_k), & \textit{if a random } \xi \textit{ is } 0 \\ x_k + \Delta(t, x_k - EM), & \textit{if a random } \xi \textit{ is } 1 \end{cases} \tag{5}$$

where, IM and EM are the immigration and emigration rates of the variables x_k. The function $\Delta(t, y)$ returns a value in the range [0,y] such that $\Delta(t, y)$ approaches zero as t increases. This Eq. (5) makes the mutation operator to search the space uniformly at initial stages (when t is small), and very locally at forthcoming stages. This search technique increases the probability of generating a new number close to its follower than a random choice. The function $\Delta(t, y)$ is evaluated as below:

$$\Delta(t, y) = y \cdot \left(1 - \eta^{\left(1 - \frac{t}{T}\right)^p}\right) \tag{6}$$

where η is a random number between [0,1], T specifies the maximum generation, p is a system parameter that determines the degree of dependency on the generation number. This proposed non-homogenous mutation operation is applied in the mutation process of conventional BBO to increase the convergence rate and based on this proposed NHBBO algorithm is developed.

3.3.2 Proposed Non-homogenous Biogeography Based Optimization (NHBBO) Algorithm

Generally, researchers applied various concepts for generating the feasible solutions by controlling the amount of diversity. Mutation process in conventional BBO increases the diversity of the population. It can be noted that the mutation rate changes the habitat's suitability index variable (SIV) in a random manner based on the mutation rate. Also, the mutation rate will be inversely proportional to the probability of species—count. Thus in basic BBO, when a solution is selected for mutation, it will be replaced by means of a randomly generate new solution set. Hence, this random mutation is found to affect the exploration capability of basic BBO. To improve the exploration capability of BBO, mutation process is modified as given in Sect. 3.3.1 to refine the habitats and perform in a better manner to achieve optimal solution.

In the conventional BBO [22] algorithm, the probability of selection of species (P_s) that changes from a particular time to an another time is given by,

$$P_s(t + \Delta t) = P_s(t)(1 - \lambda_s \Delta t - \mu_s \Delta t) + P_{s-1} \lambda_s \Delta t + P_{s+1} \mu_{s+1} \Delta t \tag{7}$$

where, λ_s and μ_s are the immigration and emigration rates when there are S species in the habitat. In the proposed NHBBO algorithm, no changes are made in the migration part so as to maintain the exploitation ability. The modification made in the mutation part with non-homogenous criteria increases the exploration capability. Thus the proposed NHBBO results in a balanced exploration and exploitation ability of the algorithm. The pseudo code for the proposed NHBBO algorithm is given in Table 4.

The proposed NHBBO algorithm is utilized in this paper to carry out weight optimization in multi-point decision making algorithm and to select the best RAT for the heterogeneous networks considered. The following section presents the applicability of the proposed hybrid PFS–NHBBO algorithm for selection of RAT in wireless networks for the considered data sets.

4 Simulation Results

In this paper, a heterogeneous wireless network with two types of radio access technologies of variant coverage ability is considered i.e., WWAN and WLAN. Figure 1 shows the service area made up of numerous hexagonally shaped partitioned cells. From Fig. 1, it is noted that each of this hexagonal cell possess a base station with an antenna at the center of the cell and mobile units for the respective locations are uniformly distributed over the hexagonal cell area considered. Around 100–1000 mobile users were considered with 100 users as increment point. The selection of best RAT (WWAN or WLAN) lies in the hand of the mobile users. Table 1 shows the parameters considered for deciding the selection of best RAT along with their rage specifications. Table 5 provides the sample data set [20] of considered users with the constraint parameters fixed—speed of the mobile terminal, received signal strength, network coverage, packet delay and data rate, which are used for RAT selection process (1000 users were considered). The entire proposed algorithmic approach was rum in MATLABR2009 environment and executed in Intel Core2 Duo Processor with 2.27 GHz speed and 2.00 GB RAM.

Table 4 Pseudo code for proposed NHBBO algorithm

Start
Initialize the population randomly
Compute the fitness and sort the population from best to worst
Initialize probability of species count of each Habitat
When The termination criteria is not met do
Save the best habitats in a temporary array (Elitism)
For each habitat, map the habitat suitability index (HSI) to number of species S, λ and μ
Choose the immigration island based on μ
Migrate randomly selected SIVs based on the selected island in previous step
Mutate the population probabilistically as per Eqs. (4) and (5)
Compute the fitness and sort the population from best to worst
Perform the checking condition
Refine the habitats
end if
Sort the population
Check for feasible solution and the presence of a similar habitat
Stop

Table 5 Sample dataset of mobile users for input parameters (N, SS, NC, δ and β)

S. no.	N (WWAN and WLAN)	SS_1 (WWAN)	SS_2 (WLAN)	NC (WWAN)	NC (WLAN)	δ (WWAN and WLAN)	β (WWAN and WLAN)
1	0.985	−91.102	−94.392	8.236	1.750	356.869	265.062
2	8.944	−100.093	−71.701	5.166	7.027	281.502	92.153
3	5.409	−100.392	−57.327	6.797	0.366	711.129	249.829
4	1.202	−80.724	−67.569	5.251	3.258	590.609	264.175
5	4.151	−88.607	−85.056	1.807	2.554	476.555	139.514
6	6.537	−104.384	−58.816	9.326	1.635	451.341	96.362
7	5.774	−77.367	−65.267	4.400	2.576	715.045	342.473
8	0.642	−82.442	−93.567	7.673	6.712	281.508	292.420
9	4.191	−83.544	−72.897	3.908	8.161	137.763	334.689
10	7.891	−95.477	−64.273	8.523	5.056	138.602	235.284
11	4.440	−85.930	−57.455	0.600	8.668	366.157	322.704
12	6.068	−76.496	−93.443	4.860	8.913	503.781	195.838
13	0.185	−82.137	−82.177	8214	4.447	877.049	141.257
14	9.218	−86.537	−65.403	7.382	1.763	449.444	385.412
15	9.169	−92.829	−58.227	4.103	8.937	42.298	389.183
And so on up to 1000 users							

Table 6 Computed outputs of parallel fuzzy systems

WWAN selection—fuzzy output				WLAN selection—fuzzy output			
NO_1	SSO_1	NCO_1	QoS_1	NO_2	SSO_2	NCO_2	QoS_2
0.125	0.625	0.875	0.541	0.331	0.331	0.125	0.541
0.875	0.125	0.651	0.411	0.625	0.625	0.780	0.627
0.676	0.125	0.766	0.625	0.875	0.875	0.125	0.375
0.125	0.875	0.665	0.625	0.727	0.727	0.347	0.375
0.452	0.625	0.125	0.375	0.625	0.625	0.253	0.875
0.751	0.125	0.875	0.572	0.875	0.875	0.125	0.427
0.706	0.875	0.489	0.782	0.778	0.778	0.257	0.375
0.125	0.875	0.824	0.482	0.365	0.365	0.761	0.659
0.457	0.875	0.421	0.375	0.625	0.625	0.875	0.668
0.858	0.125	0.875	0.375	0.776	0.776	0.633	0.875
0.495	0.768	0.125	0.548	0.875	0.875	0.875	0.550
0.725	0.875	0.583	0.625	0.370	0.370	0.875	0.375
0.125	0.875	0.875	0.625	0.625	0.625	0.496	0.375
0.875	0.722	0.805	0.625	0.756	0.757	0.125	0.375
0.875	0.625	0.445	0.375	0.875	0.875	0.875	0.625
0.875	0.125	0.125	0.375	0.625	0.625	0.125	0.875
And so on up to 1000 users							

4.1 Output of Proposed PFS for Considered Mobile Users

For the considered data samples of 1000 users with the sample data set as shown in Table 5, to start with proposed PFS was applied and the fuzzy system output for the respective input parameters are computed. For generating fuzzy system outputs, Mamdani fuzzy inference system editor is used for the purpose. The degree of membership of the respective RAT selected for the given input variables with fuzzy rules evaluated will be the output of PFS module i.e., the output of PFS will be membership values (only between 0 and 1) of each of the input parameter considered. Table 6 shows the output of the PFS computed for the given input data. Only few samples of the outputs are shown in Table 6. From Table 6, it is observed that NO_1, SSO_1, NCO_1 and QoS_1 indicate the probability of selection of WWAN network and NO_2, SSO_2, NCO_2 and QoS_2 indicate the probability of selection of WLAN network. The outputs from the PFS are sent to the Multi-point decision making algorithm—NHBBO module to optimize the weighting coefficients and to select the best RAT for heterogeneous network.

4.2 Output from the Proposed NHBBO Algorithm for RAT Selection

In this module, the outputs from the proposed PFS are given as input to the multi-point decision making algorithm and NHBBO part. The ultimate aim of the proposed NHBBO algorithm is to optimize the weighting coefficients and select the best RAT. Employing the proposed NHBBO algorithm, optimal weights are assigned to the parametric coefficients resulting in better user satisfaction ratio. The proposed NHBBO is simulated for 25 trial runs with random values generated for the species generated and their control parameters. The optimal solution is arrived for the following settings of NHBBO algorithm:

Maximum generation	200
Species size	40
Initial weights	Random generation

At the time of simulation, the ranges of users satisfied percentage is evolved and are tuned at the same time. Finally, the value of the percentage of satisfied users will be counted and based on that best RAT will be selected. Table 7 shows the optimal weighting factors user's satisfied percentage computed for the proposed Multi-point and NHBBO algorithm.

It can be noted from Table 7 that the proposed NHBBO algorithm has evolved solution with an average percentage of user satisfaction being 89 %. Table 8 shows the optimized solutions computed employing the proposed multi-point and NHBBO algorithm. The ranking coefficients of WWAN and WLAN network are computed by the optimal weighting factors. The selection of best network is performed by comparing the ranking value computed for both the RAT networks.

Ranking values of the WWAN and WLAN are computed using the equations stated in Eqs. (2) and (3) and are tabulated in Table 8. The optimal weights to compute the ranking factor is carried out using the proposed NHBBO algorithm. Based on the ranking values computed best RAT (either WWAN or WLAN) is selected. Thus the proposed algorithm is employed to select the best RAT for the considered heterogeneous wireless networks.

5 Discussion and Performance Comparison

From the above section, it is observed that for the set number of users, in the range of 100–1000 users, in the incremental steps of 100 users simulation is carried out and the solutions computed are given in Tables 6, 7 and 8. The computed results of the proposed

Table 7 Optimal weighting factors of proposed NHBBO algorithm

Number of users	Optimal weighting factors				Percentage of satisfied users
	w_1	w_2	w_3	w_4	
100	0.5321	0.0651	0.1236	0.0611	89.21
200	0.4503	0.0874	0.1492	0.0713	89.96
300	0.6125	0.0765	0.1542	0.0983	88.42
400	0.5487	0.0712	0.1781	0.0533	89.01
500	0.4961	0.0643	0.1590	0.0620	89.92
600	0.7012	0.0697	0.1672	0.0781	89.34
700	0.6999	0.0702	0.1590	0.0654	89.56
800	0.5142	0.0842	0.1420	0.0716	89.09
900	0.6466	0.0737	0.1700	0.0645	89.46
1000	0.6124	0.0652	0.1287	0.0971	89.59

Table 8 Optimal solutions for RAT selection using proposed NHBBO

Ranking value for WWAN for 100 users	Ranking value for WLAN for 100 users	Best RAT network selected based on ranking values
0.119	0.0609	WWAN
0.0496	0.1190	WLAN
0.0510	0.1296	WLAN
0.1559	0.1271	WWAN
0.1128	0.0965	WWAN
0.059	0.1367	WLAN
0.1640	0.1542	WWAN
0.1547	0.1498	WWAN
0.1462	0.1208	WWAN
0.1439	0.1567	WLAN
0.0515	0.0321	WWAN
0.1265	0.1175	WWAN
0.1638	0.1501	WWAN
0.1594	0.1432	WWAN
0.1443	0.1509	WLAN
And so on up to the set number of users		

hybrid PFS–NHBBO are compared with that of the well-known algorithms for radio resource unit allocation which includes—Access Network Selection proposed by Alkhawlani and Ayesh [20] and Mobile based RAT selection as proposed by Tudzarov and Janevski [23, 24] and regular fundamental selection methodology Random Based Selection (RBS).

For RAT selection inspite of all the five parameters considered from the 4 metrics as discussed in Sect. 2, the most prominent index that leads to the best RAT selection is the 'users satisfaction rate' represented by the percentage of satisfied users. Table 9 shows the comparison of the percentage of users satisfaction for the proposed hybrid PFS–NHBBO approach with that of the methods considered from the literature [19–21, 23, 24].

Table 9 Comparison of percentage of user's satisfaction rate of proposed hybrid PFS–NHBBO approach and other methods

S. no.	Methodology adopted	Average percentage of user's satisfaction rate (%)	Computational time taken for selecting the best RAT (s)
1	Random based selection approach	41	190
2	Access network selection by Alkhawlani and Ayesh [20]	79	175
3	Mobile based RAT selection by Tudzarov and Janevski [24]	81	160
4	Proposed hybrid PFS–NHBBO algorithm	89	81

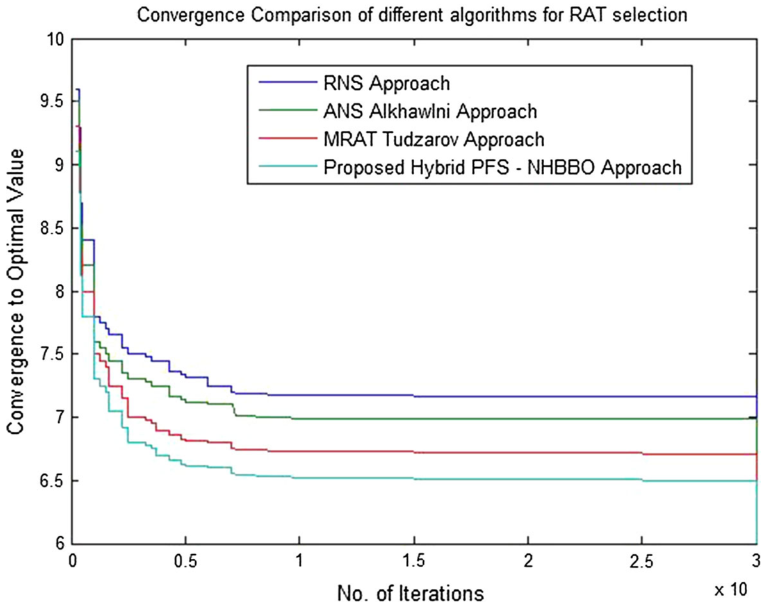

Fig. 5 Convergence plot for the proposed approach and other methods

From Table 9, it can be observed that the percentage of user satisfaction rate is better than that of the other methods considered for comparison. Also, the computational time taken for determining the best RAT for the given heterogeneous network is reduced to half the time in comparison with that of the methods available in the literature. Henceforth, it is noted that the proposed hybrid PFS–NHBBO results in a user satisfaction rate of 89 % within 81 s and proves to be better than any other methods considered for comparison. From Fig. 5 it is observed that the proposed approach converges quickly than that of the other approaches.

6 Conclusion

In this paper work has been carried out to determine the best RAT to be allocated for the mobile users in a heterogeneous wireless networks. The necessity of selection of best RAT lies in the fact that networks with multiple RATs will become the most prominent technologies in the future generation mobile networks. As a result, steps are taken in this paper to devise a suitable simple and accurate approach to select best RAT. Also, in case of heterogeneous networks, it is better to have an intelligent mechanism for selecting the network access. Considering the said factors, in this paper, the hybridization of PFSs, Multi-point decision making algorithm and proposed NHBBO is devised to select a best RAT with a higher user's satisfaction rate. The key search problem in this paper is to determine the optimal weights for the networks based on which the rank values are evaluated and resulted in selection of RAT (WWAN or WLAN). From the results computed based on the simulations carried out for the considered number of mobile users, it is observed that the proposed hybrid PFS–NHBBO approach performs better with the other methods employed for RAT selection in literature.

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