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Hybrid Approach for Radio Network Selection in Heterogeneous Wireless Networks

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Abstract

Next generation wireless network (NGWN) will be composed of multiple radio access technologies (RATs) and domains. Radio network selection (RNS) is the mechanism which decides how to select the most suitable RAT based on the discovered accesses, QoS constraints, operator policies, user preferences and available system capacity and utilization. Optimizing the selection process is an important issue of research, which leads to reduction of network signaling and mobile device power loss and on the other hand improves network quality of service (QoS) and grade of service (GoS). This paper presents and designs a multi criteria RNS solution that considers an environment with a co-existed WWAN, WMAN, and WLAN. The developed solution contains two modules. The first module resides in the user terminal. It contains a network-assisted terminal-controlled algorithm to reflect the user viewpoint in the selection process. The second module resides in the common radio resource management (CRRM) entity. It contains a terminal-assisted network-controlled algorithm to reflect the operator viewpoint of the selection decision. The developed solution uses a combined parallel fuzzy logic control and Multi-criteria decision making (MCDM) system to achieve scalable, flexible, general, and adaptable solution. The simulation results show that our solution has better and more robust performance over several reference algorithms.

Keywords: *Next generation wireless network; Radio network selection; Fuzzy logic control; Multi-criteria decision making*

1. Introduction

In the next generation heterogeneous wireless networks, a user with a multi-interface terminal may have network access for different service providers using various technologies, therefore new radio resource management (RRM) schemes and mechanisms are necessary to benefit from the individual characteristics of each RAT. In tight-coupled NGWN environments, the different RATs are connected to one common core network through common interfaces using special interworking units and the radio networks are connected to each other through a well-defined interface. To exploit the gain resulting from jointly considering the whole set of available radio resources in each RAT, a common radio resource management (CRRM) entity acts as a coordinator of the RATs specific RRM functionalities, with some new functionalities such as radio network selection (RNS), joint admission control (JAC), joint scheduling control (JSC), vertical handover (VHO) or joint congestion control (JCC). This paper covers the RNS problem that considers the selection of the most optimal and promising RAT to achieve better networks stability, resource utilization, operator benefits, user satisfaction, and quality of service (QoS) provisioning.

In the context of multi-criteria based RNS algorithms, a dynamic user-centric network selection which optimizes handover across heterogeneous networks is proposed in [1]. The proposed network selection utilizes user-defined policies and cross-layer information including physical, link and application layer. Paper [2] investigates an effective and efficient scheme that allows mobile terminals dynamically to select the most appropriate network path according to user preferences such as: cost, speed, quality, and capacity. A new algorithm for Radio Access Technology selection in heterogeneous wireless networks based on service type, user mobility and network load is presented in [3]. Performances of the proposed algorithm are evaluated by using Two-dimensional Markov chain. R. Trestian et al. [4] propose a network selection algorithm which bases its decision on the estimated energy consumption. The proposed solution enables the multimedia stream to last longer while maintaining an acceptable user perceived quality by selecting the least power consuming network. Paper [5] proposes a survey and comparison study on different weighting algorithms, which allow assigning a weight for each criterion, for network selection process based on MADM algorithms. In paper [6], an algorithm for a context-aware network selection is proposed that is based on a modified WPM for access network selection. The authors use a weight distribution method based on sensitivity analysis of WPM for the most influential criteria based on the state of user at a given time. In paper [7], an effective access network selection algorithm for heterogeneous wireless networks is proposed that combines two Multi Attribute Decision Making (MADM) methods, the Analytic Hierarchy Process (AHP) method and the Total Order Preference by Similarity to the Ideal Solution (TOPSIS) method. More specifically, the AHP method is used to determine weights of the criteria and the TOPSIS method is used to obtain the final access network ranking. D. Xueli et al. [8] introduce the basic network selection/handover procedure in heterogeneous networks, and based on the network selection procedure, the Analytic Hierarchy Process based network selection algorithm (AONA) is proposed to consider the QoS requirements of traffics and different access networks situations etc. to give the best choice for the users.

In [9], G. Koundourakis et al. introduce an operator-centric approach for access selection in a co-existed UMTS, WLAN and DVB-T heterogeneous environment. The proposed approach focuses on the optimization of the resource utilization, while ensuring acceptable QoS provision to the end users. In [10] a centralized operator-centric selection scheme, aiming to optimally distribute the end users to the heterogeneous networks, in the sense of maximizing the global spectrum efficiency is proposed. [11] has described adaptation of ELECTRE, MCDM tool, for ranking network alternatives during the network selection process. TOPSIS, MCDM tool, is applied to the problem of network selection [12]. The proposed algorithm depends upon the QoS requirements of the service being requested by the user device. J. Noonan et al. in [13] examine the RNS decision, and propose that the selection decision is made by the client application by considering network characteristics and cost. [14] proposes a net utility-based network selection algorithm, where a utility function is used to reflect the user satisfaction level to QoS and a cost function is used to reflect the cost for service. In [15] A. Iera et al. present a multi-criteria network selection algorithm that relies on a suitably defined cost function, which takes into account metrics reflecting both network related and user preference related objectives. CRRM strategies based on reinforcement learning mechanisms that control fuzzy-neural joint admission control and bit rate allocation algorithms to ensure certain QoS constraints are presented by L. Giupponi et al. and R. Agusti et al. [16, 17, 18]. A. Wilson et al. [19] propose a decision strategy for optimal choice of wireless access network using FL as the inference mechanism. [20] provided extensive simulations to demonstrate multi attribute decision making (MADM) models feasibility for modeling network selection and its appropriateness for selecting reasonable networks in various scenarios.

In general, the above mentioned RNS algorithms could be categorized into conventional multi criteria based algorithms or AI based algorithms. In the first category, the algorithms do not take into account the complexities and uncertainties that arise from the different characteristics and natures of the different RATs. For these algorithms, it is not easy task to incorporate the accumulated human knowledge about the problem and the only method to adapt the algorithms is to change the criteria weights randomly to get better results. The mentioned AI-based algorithms do not address the viewpoints of both the user and operator on the selection decision making. They do not consider the trade-off between criteria of the RNS problem and do not specify the importance and sensitivity of each criterion to the selection problem. The current intelligent multi criteria based algorithms suffer from scalability and modularity problems. Usually they cannot cope easily with the increased numbers of RATs and criteria in the NGWN because they use the traditional FL, where all the inputs are using one big FL system.

The main contribution of this paper is the development of a new class of RNS algorithms that are based on hybrid parallel fuzzy logic (FL) based decision and analytic hierarchy process (AHP) MCDM systems. This class of algorithms represents the first attempt to develop adaptive, flexible, and scalable RNS algorithms that are utilizing the advantages of hybrid parallel FL decision making systems and AHP method. FL helps out in reducing the complexity involved on the NGWN in several ways. First, the data, information, and measurements that have to be taken into account in the RNS are in general very dissimilar, imprecise, contradictory, and coming from different sources. As a result of that, a FL based solution has been thought to be a good candidate for reaching suitable RNS decisions from such imprecise and dissimilar information. Second, RNS solution has to be able to response to the changing conditions of the NGWN environments and the accumulated experience of the operators and users. FL based solution is easy to modify by tuning and adjusting the inference rules and membership functions. The application of parallel FL rather than traditional FL achieves more advantages for the RNS solution. The idea of the parallel FLC reduces the number and complexity of the inference rules used in the FL based solution, which helps out in achieving more scalable solutions. In a very complex and uncertain environments such as NGWN, MCDM can sufficiently reduce the uncertainty and doubt about the alternatives and allows a reasonable choice to be made from among them.

This paper extended our work in [21, 22, 23, 24]. In this paper, three RATs have been considered rather than two RATs. Our previous work is based on single module that has one generic RNS algorithm that considers both the operator benefits and user satisfaction. In this paper, our RNS solution is based on two modules. In the first module, a network-controlled with mobile assistance RNS algorithm that considers the operator benefits and network conditions and takes into account the user preferences is presented. The second module is based on a mobile-controlled with network assistance algorithm that mainly considers the user preferences. Also, more reference algorithms have been used in his paper. In addition, more comprehensive results analysis has been conducted in this paper.

2. The Radio Network Selection Solution

For the tight-coupled NGWN networks, both the CRRM and user terminal entities have the abilities to make the decision because both entities have the abilities and authority to collect the required information. Hence, this paper suggests RNS solution that contains two modules. The first module resides in the user terminal. It contains a network-assisted terminal-controlled algorithm to reflect the user viewpoint in the selection decision. The second module resides in the CRRM entity. It contains a terminal-assisted network-controlled algorithm to reflect the operator viewpoint of the selection decision. The terminal-assisted network-controlled algorithm is mainly based on the operator policies and network conditions and it takes into account the user selection sent from the user terminal. The main steps and interactions in our solution when a new service request is initialized are explained as follows:

1) When the MT is turned on, a list of the available networks is detected. While roaming on the NGWN, any new detected RAT is added to the available list.
2) When the user asks for a new service, the user has two available options, either manual or automated selection. In both cases, the user is authorized and the selection is sent to the CRRM entity in the NGWN.
3) The user selection is sent to the operator software module (OSM) resides in the CRRM. At the same time, the user selection is used as one of the criteria inputs in the OSM. The importance of the user preferred selection is specified using the weight of the user preferences criteria in the OSM. Actually the weight of the user preferences criteria in the OSM can be different from one user to another according to his/her priority.
4) The OSM chooses the most suitable radio network and assign it to the user. Then, the OSM asks the joint resource allocation module or the local resource allocation module of the selected network to assign the required resources to the user.
5) If the user request has been blocked, the OSM has to find another possible selection.

3. The Operator Software Module (OSM)

OSM based on a network-controlled terminal-assisted RNS algorithm is developed in this section. The algorithm has two main components, the FL based control component and the MCDM component. Figure 1 shows the components of the OSM.

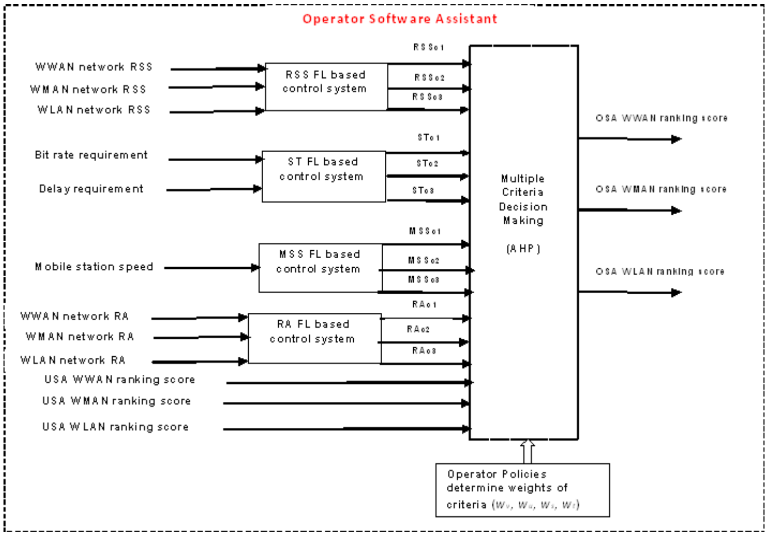

Figure 1. Operator Software Module

3.1 The FL based Control Component

Our OSM contains four FL based subsystems. Each subsystem considers one of the operator important selection criteria. The RSS subsystem considers the received signal strength criterion. The MSS subsystem considers the mobile station speed criterion. The ST subsystem considers the service type criterion. The RA subsystem considers the resources availability criterion. RSS subsystem has three input variables, RSS_1 to describe the received signal strength from the WWAN network, RSS_2 to describe the received signal strength from the WMAN network, and RSS_3 to describe the received signal strength from the WLAN network. MSS subsystem has only one input variable *MSS* to describe the mobile station speed. ST subsystem has two input variables, the first is *DelayReqc* to describe the one-way delay needed for the required service and the second is *RateReqc* to describe the bit rate needed for the required service. RA subsystem has three input variables, RA_1 to describe the resources availability in the WWAN network, RA_2 to describe the resources availability in the WMAN network, and RA_3 to describe the resources availability in the WLAN network. Every input variable has three membership functions {Low, Medium, High}. Figure 2 shows the membership functions of the input variables RA_2 and *MSS* as samples. Every subsystem has three output variables, the first variable is to describe the probability of acceptance for the new user in the WWAN network, the second variable is to describe the probability of acceptance for the new user in the WMAN network, and the third variable is to describe the probability of acceptance for the new user in the WLAN network. Each output variable has four membership functions {TR (Totally Reject), PR (Probability Reject), PA (Probability Accept), and TA (Totally Accept)}. The subsystems output variables are RSS_{c1}, RSS_{c2} and RSS_{c3} for RSS subsystem, MSS_{c1}, MSS_{c2} and MSS_{c3} for MSS subsystem, ST_{c1}, ST_{c2} and ST_{c3} for ST subsystem, and UP_{c1}, UP_{c2} and UP_{c3} for UP subsystem. Figure 3 shows RSS_{c1} variable with its membership functions as a sample for the output variables.

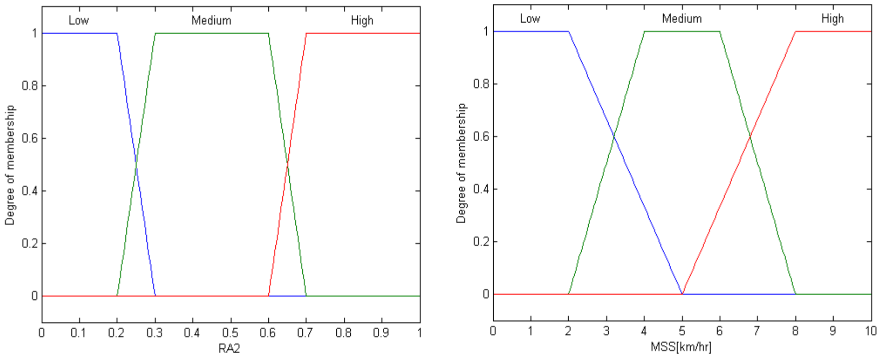

Figure 2. Membership Functions of some Input Variables

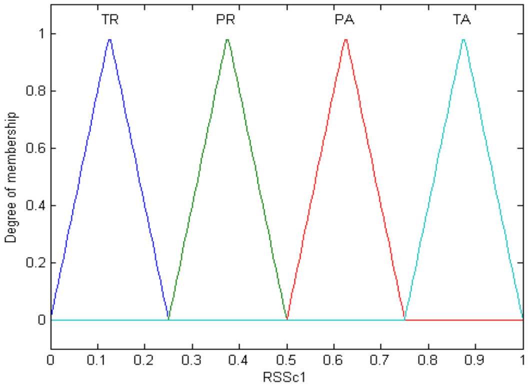

Figure 3. Membership Function of Output Variable RSS_{c1}

3.2 The MCDM Component

The MCDM system has to rank the considered alternatives according to their attractiveness. The MCDM system aims to achieve the highest number for satisfied users, the highest number of the users who get better quality, and to achieve WWAN resources utilization by increasing the usage of the low cost networks (i.e., WLAN). There are three alternatives for the MCDM, the first one is a WWAN network, the second one is a WMAN network and the third one is a WLAN network. The input criteria of the MCDM are the MSS, RSS, ST, and RA. The AHP decision making tool is used. The steps of applying the AHP to the RNS problem are described as follows.

Step1: the pair-wise comparison of criteria: the criteria pair-wise weight comparison matrix *CPWC* can be described as in equation 1.

$$CPWC = \begin{pmatrix} W_{11} & W_{12} & W_{13} & W_{14} \\ W_{21} & W_{22} & W_{23} & W_{24} \\ W_{31} & W_{32} & W_{33} & W_{34} \\ W_{41} & W_{42} & W_{43} & W_{44} \end{pmatrix} \tag{1}$$

W_{ij} is the pair-wise comparison weight that reflects the relative importance of criterion *i* with respect to the criterion *j*. If $i=j$ then $W_{ij}=1$ otherwise

$$W_{ij} = 1/W_{ji} \tag{2}$$

In equation 1, W_{1j} is the pair-wise comparison weights between the RSS criterion and other criteria. W_{2j} is the pair-wise comparison weights between the MSS criterion and the other criteria. W_{3j} is the pair-wise comparison weights between the ST criterion and the other criteria. W_{4j} is the pair-wise comparison weights between the RA criterion and the other criteria.

Step2: calculating the criteria priority vector or the criteria normalized weights: to calculate the criteria normalized weights *CNW*, the geometric mean *GM* is used. In general, the geometric mean is the nth root of the product of the n pair-wise comparison weights of the criterion. In our case, four criteria have been used, so *GM* is the 4th root of the product of the 4 pair-wise comparison weights of the criterion. In general, the geometric mean of the *i* criterion's weight GM_i can be calculated as in equation 3

$$GM_i = \sqrt[4]{\Pi_{j=1}^{4} W_{ij}} \tag{3}$$

For example, the geometric mean of the RSS criterion weight *GM1* can be calculated as shown in equation 4.

$$GM_1 = \sqrt[4]{W_{11} \cdot W_{12} \cdot W_{13} \cdot W_{14}} \tag{4}$$

After calculating the geometric mean, the normalized weight of the different criteria CNW is calculated. In general, the normalized weight of the *i* criterion *CNWi* can be calculated by dividing its geometric mean GM_i by the sum of the geometric means of all the criteria as shown in equation 5.

$$CNW_i = \frac{GM_i}{\sum_{j=1}^{4} GM_{ij}} \tag{5}$$

The normalized weight for the RSS, MSS, ST, and RA criteria can be calculated as shown in equations 6, 7, 8, and 9 respectively.

$$CNW_{RSS} = \frac{GM_{RSS}}{GM_{RSS} + GM_{MSS} + GM_{ST} + GM_{RA}} \tag{6}$$

$$CNW_{MSS} = \frac{GM_{MSS}}{GM_{RSS} + GM_{MSS} + GM_{ST} + GM_{RA}} \tag{7}$$

$$CNW_{ST} = \frac{GM_{ST}}{GM_{RSS} + GM_{MSS} + GM_{ST} + GM_{RA}} \tag{8}$$

$$CNW_{PR} = \frac{GM_{RA}}{GM_{RSS} + GM_{MSS} + GM_{ST} + GM_{RA}} \tag{9}$$

Step 3: pair-wise comparison of alternatives' scores with respect to criteria: three alternatives WWAN, WMAN, and WLAN are considered. Arrays of dimensions 3X3 are used to represent the pair-wise comparison matrices of alternatives' scores with respect to the different criteria. Equation 10 shows a general pair-wise comparison matrix of alternatives' scores *APS* with respect to one criterion.

$$APS = \begin{pmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{pmatrix} \tag{10}$$

S_{ij} is the pair-wise comparison of the *i* and *j* alternatives' scores with respect to one criterion. For RSS criterion, S_{ij} is calculated according to equation 11.

$$S_{ij} = RSSc_i / RSSc_j \tag{11}$$

The pair-wise comparison of alternatives' scores S_{ij} with respect to MSS criterion is calculated according to equation 14.

$$S_{ij} = MSSc_i / MSSc_j \tag{12}$$

The pair-wise comparison of alternatives' scores S_{ij} with respect to ST criterion is calculated according to equation 14.

$$S_{ij} = STc_i / STc_j \tag{13}$$

The pair-wise comparison of alternatives' scores S_{ij} with respect to RA criterion is calculated according to equation 14.

$$S_{ij} = RAc_i / RAc_j . \tag{14}$$

Step4: calculating the alternatives normalized scores with respect to criteria: to calculate the normalized score for alternative *i*, again the geometric mean is used. Since three alternatives are considered, the geometric mean for the alternative normalized score is the 3rd root of the product of the 3 pair-wise scores of the alternative. In general, the geometric mean of the *i* alternative's score with respect to one criterion GM_i can be calculated as shown in equation 15.

$$GM_i = \sqrt[3]{\Pi_{j=1}^{3} S_{ij}} \tag{15}$$

For example the geometric mean of the WWAN score can be calculated as shown in equation 16.

$$GM_{WWAN} = \sqrt[3]{S_{11} \cdot S_{12} \cdot S_{13}} \tag{16}$$

Then the normalized score of the *i* alternative $OANS_i$ with respective to one criterion can be calculated by dividing its geometric mean by the sum of the geometric means of all the alternatives as in equation 17.

$$OANS_i = \frac{GM_i}{\sum_{j=1}^{3} GM_j} \tag{17}$$

The normalized weight for the WWAN, WMAN, and WLAN alternatives can be calculated as shown in equations 18, 19, and 20 respectively.

$$OANS_{WWAN} = \frac{GM_{WWAN}}{GM_{WWAN} + GM_{WMAN} + GM_{WLAN}} \tag{18}$$

$$OANS_{WWAN} = \frac{GM_{WWAN}}{GM_{WWAN} + GM_{WMAN} + GM_{WLAN}} \tag{19}$$

$$OANS_{WWAN} = \frac{GM_{WWAN}}{GM_{WWAN} + GM_{WMAN} + GM_{WLAN}} \tag{20}$$

Step5: calculating the alternatives total scores and identifying the preferred alternative: to identify the preferred alternative, for each alternative *j*, the normalized score with respect to criterion *i* (i.e., $OANS_{ij}$) is multiplied by the corresponding normalized weight of criterion *i*

(i.e., *CNWi*) and the results for each alternative with respect to different criteria is summed. The preferred alternative will have the highest total score *OATS*. The total score *OATSj* for alternative j can be calculated according to equation 21.

$$OATS_j = \sum_{i=1}^{4} CNW_i \cdot OANS_{ij} \tag{21}$$

4. The User Software Module (USM)

USM that is based on based a terminal-controlled network-assisted RNS algorithm is developed in this section. The algorithm has two main components, the FL based control component and the MCDM component. Figure 4 shows the components of the USM.

4.1. The FL based Control Component

Our USM contains four FL based subsystems. Each subsystem considers one of the user important selection criteria. The RELIABILITY subsystem considers the subjective reliability criterion. The SECURITY subsystem considers the subjective security criterion. The BATTERYPOWER subsystem considers the battery power criterion. The PRICE subsystem considers the user preferred price criterion. PRICE subsystem has only one input variable Price to describe the user preferred price. RELIABILITY subsystem has only one input variable Reliability to describe the user preferred reliability criterion. SECURITY subsystem has only one input variable Security to describe the user preferred security. BATTERYPOWER subsystem has only one input variable Battery power to describe the importance of battery power for the user.

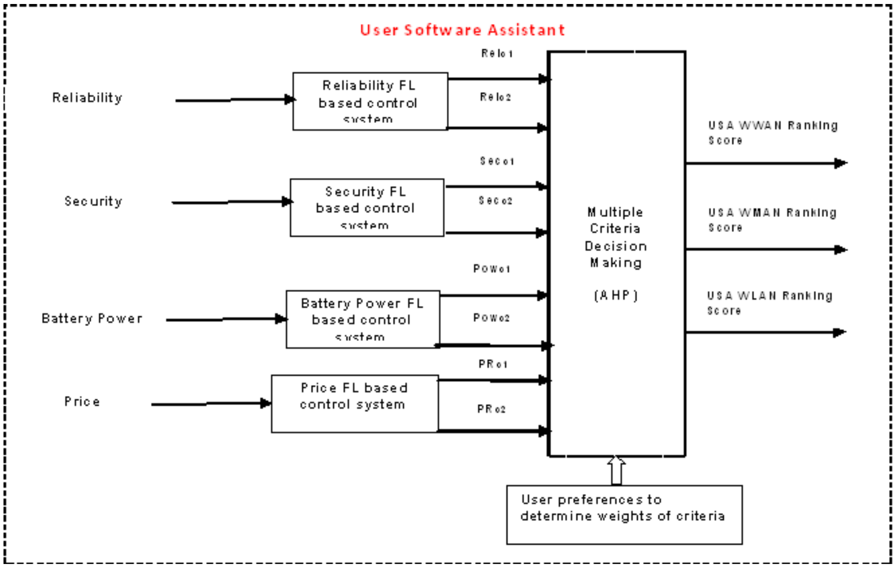

Figure 4. User Software Module

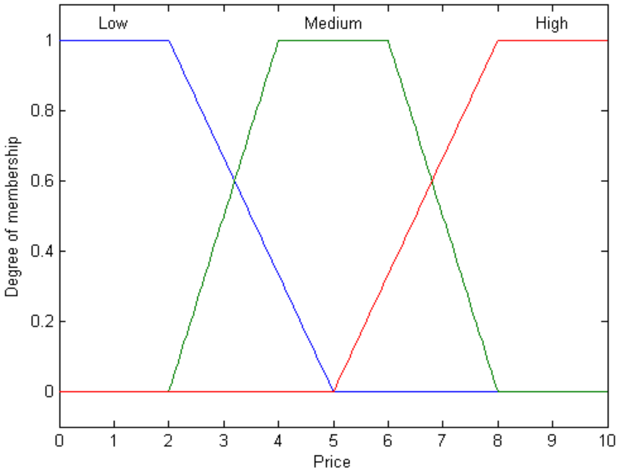

Figure 5. The Membership Functions of the Input Variable Price

Every input variable has three membership functions {Low, Medium, High}. Each input variable is described using a scale of ten degrees between 0 and 10. Higher degree represents tighter requirements for the input criterion from the user. Figure 5 shows the input variable Price membership functions as an example. As shown in Figure 4, every subsystem has three output variables, the first variable is to describe the probability of acceptance for the new user in the WWAN network, the second variable is to describe the probability of acceptance for the new user in the WMAN network, and the third variable is to describe the probability of acceptance for the new user in the WLAN network. All the output variables have similar membership functions like what is shown in Figure 3.

4.2 The MCDM Component

Again for the USM, enhanced version of AHP has been used. The ranking values of WWAN, WMAN and WLAN networks are calculated according the steps mentioned in the subsection 3.2. Using USM, the preferred alternative will have the highest total score *PATS*. The total score $PATS_j$ for alternative *j* can be calculated according to equation 22.

$$PATS_j = \sum_{i=1}^{4} CNW_i \cdot PANS_{ij} \quad (22)$$

PAN S_{ij} is he normalized score with respect to criterion *i* for alternative *j*. CNW_i is the corresponding normalized weight of criterion *i*.

5. The Simulation Environment

A modified version of MATLAB based simulator called RUNE [25] has been used. The simulation environment defines a system model, a mobility model, a propagation model, and services model. The system model considers the coexistence of three types of wireless access networks. The first network is a CDMA based WWAN with seven macro cells and cell radius of 1000m. The second one is a CDMA based WMAN with twelve macro cells and cell radius of 500m. The third one is a CDMA based WLAN with eighty four micro cells and cell radius of 100m. All cells have standard hexagonal shapes with Omni-directional antennas.

The mobiles are randomly distributed over the system. In every slot each mobile is moved a random distance in a random direction at defined time steps. The movement pattern of each mobile depends on the velocity and acceleration. The velocity is a vector quantity with magnitude and direction. The velocity of the *ith* mobile is updated according to equation 23.

$$V_i = V_{i-1} \cdot P + \sqrt{1 - P^2} \cdot V_m \cdot X \tag{23}$$

where V_i is the complex speed [m/s]. V_{i-1} is the complex speed in the previous time step. X is a Rayleigh distributed magnitude with mean 1 and a random direction. V_m is the mean speed of mobiles. P is the correlation of the velocity between time steps. P depends on both a_{mean} which is the mean acceleration of the mobile user and V_{mean}. V_m has been set to 10 [m/s] and the mean acceleration has been set to 2 [m/s^2].

The propagation model simulates the different losses and gains during the signal propagation between the transmitter and the receiver in the system environment. The wireless propagation model used in this paper is described in a logarithmic scale as in equation 24.

$$G = G_D + G_F + G_R + G_A \tag{24}$$

Equation 24 contains four components, the first component is the distance attenuation G_D that is calculated by Okumura-Hata formula. The second component is the shadow fading G_F that is modeled as a log-normal distribution with standard deviation of 6 dB and 0 dB mean. The third component is the Rayleigh fading G_R that is modeled using a Rayleigh distribution. The forth component is the antenna gain G_A that adds the antenna gain in dB.

Adaptive service model is considered in our simulation. The service *i* is mainly characterized by its bit rate requirement ”*RateReqc*” and delay requirement ”*DelayReqc*”. The users are generated according to Poisson process. The service holding time is exponential distribution with mean holding time equals to 150 seconds.

6. The Results Study

Four different reference algorithms are simulated and evaluated against our proposed solution. The first algorithm is based on a random based selection. The second solution is a terminal speed based selection. The third solution is a service type based selection. The forth algorithm is a resources availability based algorithm. Some simulation results for different sets of users are presented in this section.

Table 1: P_u Values in all algorithms

No. of Users	Our solution	MSS selection	Random selection	ST selection	RA selection
409	0.54	0.457	0.402	0.439	0.435
538	0.571	0.440	0.455	0.411	0.419
667	0.602	0.453	0.441	0.423	0.427
799	0.622	0.466	0.4618	0.416	0.424
934	0.617	0.4675	0.382	0.407	0.415

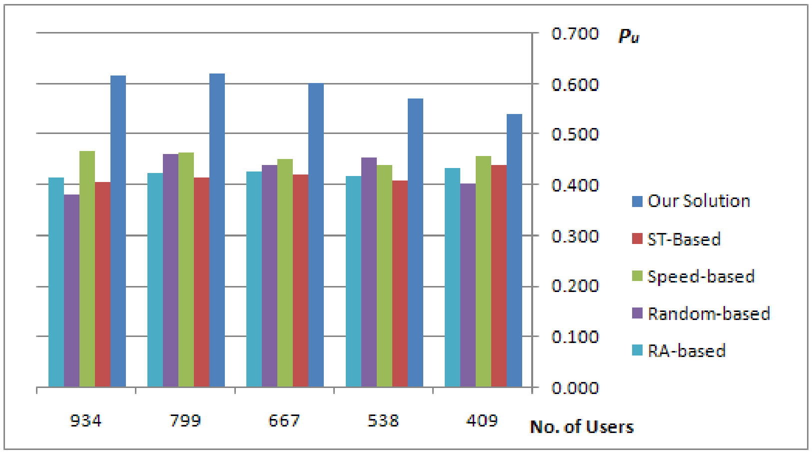

Figure 6. P_u Values for all Algorithms

Table 1 and Figure 6 illustrate some numerical results for the P_u values in all algorithms. The results show that our solution achieve good performance enhancement over all algorithms. On average, our algorithm achieves around 13%, 16%, 17%, and 17% enhancement over terminal-speed based, random based, service based , and resources availability based selection algorithms respectively. Better results can be gained if more suitable weights are used.

Table 2. P_q Values in all Algorithms

No. of Users	Our solution	MSS selection	Random selection	ST selection	RA selection
409	0.575	0.439	0.485	0.3385	0.328
538	0.589	0.399	0.389	0.375	0.355
667	0.515	0.4365	0.423	0.357	0.336
799	0.617	0.436	0.441	0.396	0.374
934	0.466	0.399	0.463	0.360	0.345

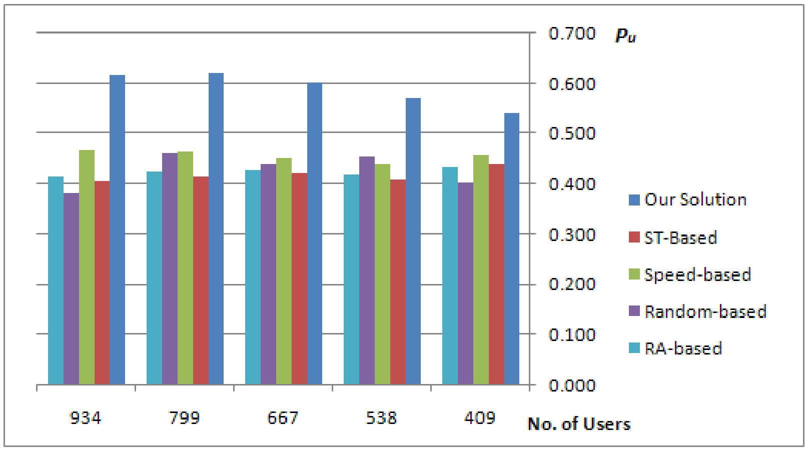

Figure 7. P_q Values for all Algorithms

Table 2 and Figure 7 illustrate some numerical results for the P_q values in all algorithms. The results show that our solution achieve significant performance enhancement over all algorithms. On average, our algorithm achieves around 13%, 11%, 18%, and 20% enhancement over terminal-speed based, random based, service based, and resources availability based selection algorithms respectively. Better results can be gained if more suitable weights are used.

Table 3. P_o Values in all Algorithms

No. of Users	Our solution	MSS selection	Random selection	ST selection	RA selection
409	0.485	0.476	0.43	0.366	0.44
538	0.498	0.433	0.4478	0.310	0.4678
667	0.459	0.447	0.411	0.363	0.4291
799	0.4417	0.391	0.436	0.336	0.431
934	0.5017	0.476	0.467	0.335	0.441

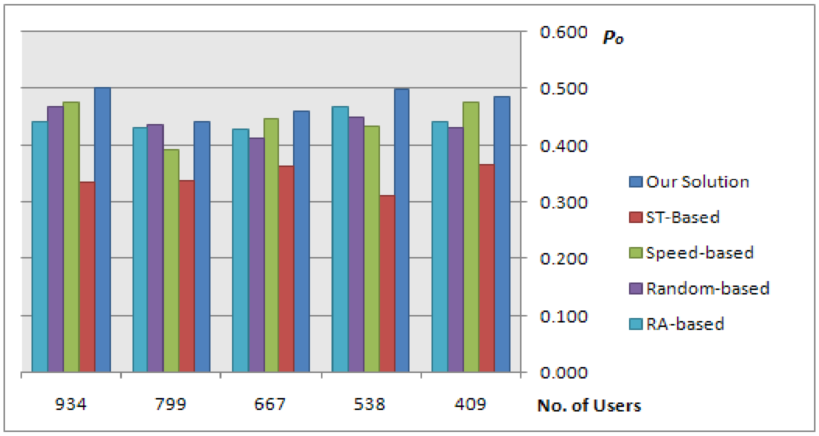

Figure 8. P_o Values for all Algorithms

Table 3 and Figure 8 illustrate some numerical results for the P_o values in all algorithms. The results show that our solution achieve comparable performance to the others in terms of the usage of low cost network. Better results can be gained if more suitable weights are used.

To check the spread of the results around the average values, the standard deviation is used [26]. After calculating the standard deviations for all sets of achieved results, we have noticed that, they are very low and around zero. This indicates that the performance does not change so much and keep performing around the average values. Consequently, stable performance metrics values are usually expected.

Although the simulation cannot be carried out at higher number of users for reasons of simplicity and computational complexity, the achieved simulation results show that our algorithm outperform the reference algorithms and a clear monotonic increasing relationship could be directly observed between the number of users and the performance metrics. To check if there is any linear relationship between the number of users and the achieved performance metrics, the Pearsons Correlation Coefficient (PCC) [26] is used. PCC investigates the strength and direction of a linear relationship between two random variables. PCC = +1 means very strong positive linear relationship. PCC = -1 means very strong negative linear relationship. PCC = 0 means no linear relationship is existed between both variables. The results shows that the values of the PCC are all around +1 which means very strong positive linear relationship and we hence expect that our algorithm will keep outperforming the other algorithms at very high number of users.

7. Conclusions and Future Work

A novel and new RNS solution has been presented in this paper. Our solution is divided into two modules to take into account the viewpoints of the user and operators. The solution gives the fair roles for both parties (i.e. operators and users). The user makes an initial selection based on four different user criteria in his equipment and then the initial selection is sent to the CRRM entity where the final selection is done based on several operator criteria and taking into account the user initial selection. The developed solution is evaluated using simulation approaches. Its performance is compared against several reference algorithms. The simulation results show that the developed solution has a better and robust performance over the reference algorithm in terms of the number of satisfied users, the operator benefits and the QoS.

Our future works can be extended in several directions. An optimum values for the weights of the different criteria can be found using a global optimization method. Also, the rules and membership functions of the fuzzy subsystems can be built or tuned using the genetic algorithms or the neural networks.

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