Intelligent Radio Network Selection for Next Generation Networks

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ABSTRACT: *In a tightly coupled Next Generation Wireless Network (NGWN), a large number of different radio access technologies (RATs) will be integrated into one common network. These RATs are owned by one operator or multi-cooperative operators. Selecting the most optimal and promising RAT is an important consideration for overall networks stability, resource utilization, operator benefits, user satisfaction, and Quality of Service (QoS) provisioning. However, choosing the best RAT is not a trivial task and there are many parameters and criteria to take into account when selecting the best access network. 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 terminalcontrolled algorithm to reflect the user viewpoint in the selection process. The second module resides in the CRRM entity. It contains a terminal-assisted networkcontrolled 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 achievescalable, flexible, general, and adaptable solution. The simulation results show that our solution has betterand more robust performance over several reference algorithms.*

Keywords: Next Generation Wireless Networks, Radio Access Technologies, Fuzzy logic control, Radio Network

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1. Introduction

Next Generation Wireless Network (NGWN) will be composed of multiple radio access technologies (RATs) and domains, 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. In [2], 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 [3] a centralized operatorcentric selection scheme, aiming to optimally distribute the end users to the heterogeneous networks, in the sense of maximizing the global spectrum efficiency is proposed. [4] 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 [5]. The proposed algorithm depends upon the QoS requirements of the service being requested by the user device. J. Noonan et al. in [6] examine the RNS decision, and propose that the selection decision is made by the client application by considering network characteristics and cost. [7] 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 [8] 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. [9], [10], [11]. A. Wilson et al. [12] propose a decision strategy for optimal choice of wireless access network using FL as the inference mechanism.

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 Simple Multi Attribute Rating Technique (SMART) 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 SMART 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 [13], [14]. 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.

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 terminalcontrolled 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 terminalassisted 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 terminalassisted 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.

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 fLow, Medium, Highg. 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 fTR (Totally Reject), PR (Probability Reject), PA (Probability Accept), and TA (Totally Accept)g. 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 ST_{c1} variable with its membership functions as a sample for the output variables.

3.2. The MCDM component

Enhanced version of Simple Multi Attribute Rating Technique (SMART) has been used. SMART is one of the simplest and most efficient MCDM methods. SMART employs relatively uncomplicated and straightforward manipulation method, which makes it stronger and easier to use in a hybrid and more complex models such as the proposed one in this paper. With the aid of parallel FL, SMART has all the capabilities required to address the specific considerations that are involved in the RNS process. SMART can be quickly and easily understood by the inexperienced decision makers. The ranking value x_j of alternative A_j is obtained simply as the weighted algebraic mean of the utility values associated with it (i.e., a_{ij}) according to equation 1.

$$x_j = \frac{\sum_{i=1}^{m} w_i a_{ij}}{\sum_{i=1}^{m} w_i} \quad j = 1, 2, \ldots n \qquad (1)$$

There are three alternatives for the MCDM, the first one is a WWAN network, the second is a WMAN network, and the third one is a WLAN network. The input criteria of the MCDM are the outputs of the FL based control subsystems in the first component. The criteria with more importance to the operator and user can be assigned higher weight. Since all the outputs of FL subsystems are in the range [0, 1], there is not any need to scale the criteria performance against alternatives.

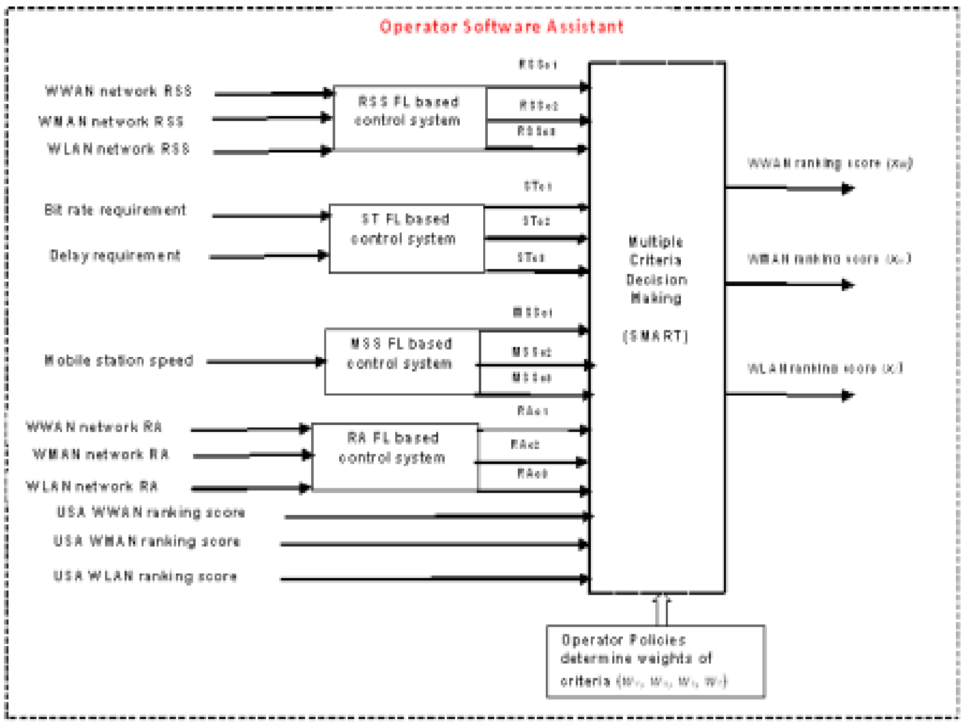

Figure 1. Operator Software Module

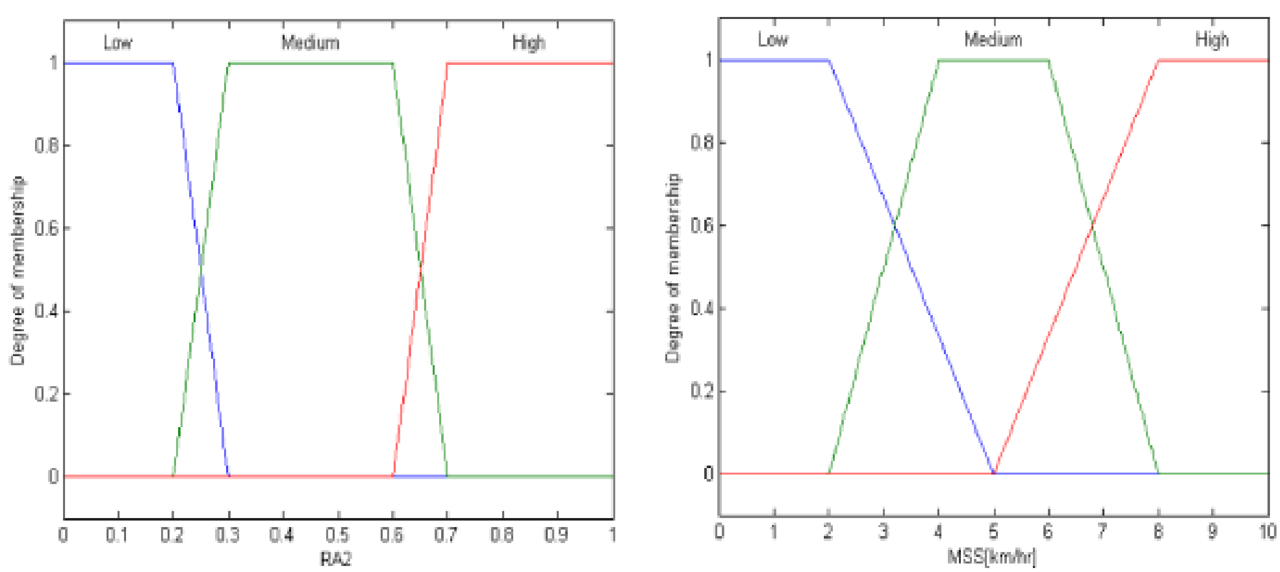

Figure 2. Membership functions of some input variables

The ranking value of WWAN x_w, the ranking value of WMAN x_m, and the ranking value of WLAN x_l are calculated as follows.

$$x_w = \frac{MSS_{c1} * W_v + RSS_{c1} * W_s + ST_{c1} * W_t + RA_{c1} * W_r}{TW_1} \quad (2)$$

$$x_m = \frac{MSS_{c2} * W_v + RSS_{c2} * W_s + ST_{c2} * W_t + RA_{c2} * W_r}{TW_1} \quad (3)$$

$$x_l = \frac{MSS_{c3} * W_v + RSS_{c3} * W_s + ST_{c3} * W_t + RA_{c3} * W_r}{TW_1} \quad (4)$$

where W_v is the assigned weight for the mobile station speed criterion. W_s is the assigned weight for the received signal strength criterion. W_t is the assigned weight for the service type criterion. W_r is the assigned weight for the resources availability criterion. TW_1 is the total weight and is calculated using 5.

$$TW_1 = W_v + W_s + W_t + W_r \quad (5)$$

4. The User Software Module (USM)

USM 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.

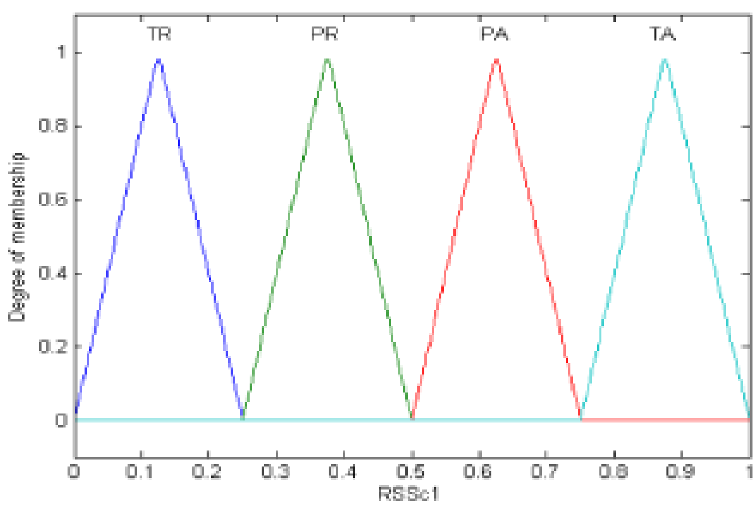

Figure 3. Membership function of output variable ST_{c1}

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 Batterypower to describe the importance of battery power for the user. Every input variable has three membership functions

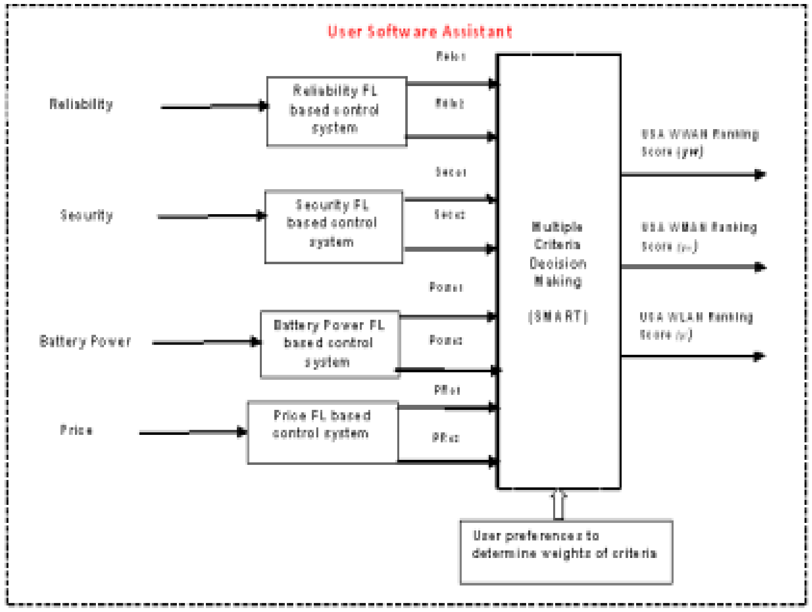

Figure 4. User Software Module

fLow, Medium, Highg. 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 **SMART** has been used. The ranking value of **WWAN** y_w, the ranking value of **WMAN** y_m, and the ranking value of **WLAN** networks y_l are calculated as follows.

$$y_w = \frac{REL_{c1} * W_e + SEC_{c1} * W_c + POW_{c1} * W_p + PR_{c1} * W_u}{TW_2} \quad (6)$$

$$y_m = \frac{REL_{c2} * W_e + SEC_{c2} * W_c + POW_{c2} * W_p + PR_{c2} * W_u}{TW_2} \quad (7)$$

$$y_l = \frac{REL_{c3} * W_e + SEC_{c3} * W_c + POW_{c3} * W_p + PR_{c3} * W_u}{TW_2} \quad (8)$$

where We is the assigned weight for the reliability criterion. Wc is the assigned weight for the security criterion. Wp is the assigned weight for the terminal power criterion. Wu is the assigned weight for the user preferred price criterion. TW2 is the total weight and is calculated using 9.

$$TW_2 = W_v + W_s + W_t + W_r \quad (9)$$

5. The Performance Evaluation

Our proposed solution is evaluated using the simulation approach. This section presents the used performance metrics and simulation models.

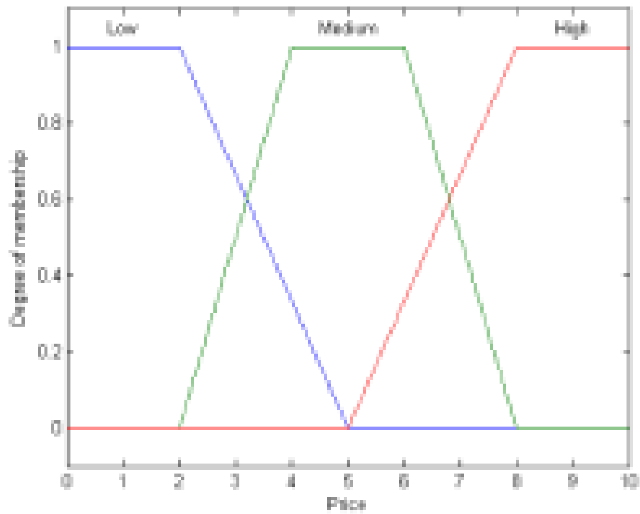

Figure 5. The membership functions of the input variable *Price*

5.1. The performance metrics

In this paper three performance evaluation metrics have been used to evaluate our algorithms. The used metrics can be described briefly as follows.

The percentage of users who are assigned to networks of their preference (P_u). This metric reflects the user point of view about the performance of the selection process.

The percentage of users who are assigned to networks with better QoS conditions. This metric reflects the QoS point of view about the performance of the selection process. For simplicity, we can use the percentage of the users who are assigned to networks with stronger received signal (P_q).

The usage percentage of the low cost network resources (i.e., **WLAN**) (P_o). This metric reflect the operator point of view because it utilizes the resources of the high cost networks (i.e., **WMAN** and **WWAN**). Simply, Po can be calculated as the percentage between the number of users in **WLAN** and the total number of users.

5.2. The simulation environment

A modified version of MATLAB based simulator called RUNE [15] 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 10.

$$V_i = V_{i-1} . P + \sqrt{1-P^2} . V_m . X \qquad (10)$$

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 11.

$$G = G_D + G_F + G_R + G_A \quad (11)$$

Equation 11 contains four components, the first component is the distance attenuation G_D that is calculated by Okumura-Hata formula presented in [16]. 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.

No.of Users	Our solution	MSS selection	Random selection	ST selection
418	0.562	0.462	0.486	0.519
512	0.525	0.498	0.506	0.518
625	0.544	0.502	0.506	0.485
720	0.561	0.476	0.489	0.464
831	0.590	0.493	0.519	0.515

Table 1. P_u values in all algorithms

6. The results study

Three 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. Some simulation results for different sets of users are presented in this section.

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 7%, 5%, and 5% enhancement over terminal-speed based, random based, and service based selection algorithms respectively. Better results can be gained if more suitable weights are used. 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 17%, 12.5%, and 13.5% enhancement over terminal-speed based, random based, and service based selection algorithms respectively. Better results can be gained if more suitable weights are used.

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.

No. of Users	Our solution	MSS selection	Random selection	ST selection
418	0.584	0.435	0.469	0.507
512	0.684	0.465	0.508	0.520
625	0.621	0.483	0.464	0.498
720	0.650	0.471	0.486	0.472
831	0.628	0.460	0.511	0.491

Table 2. P_q values in all algorithms

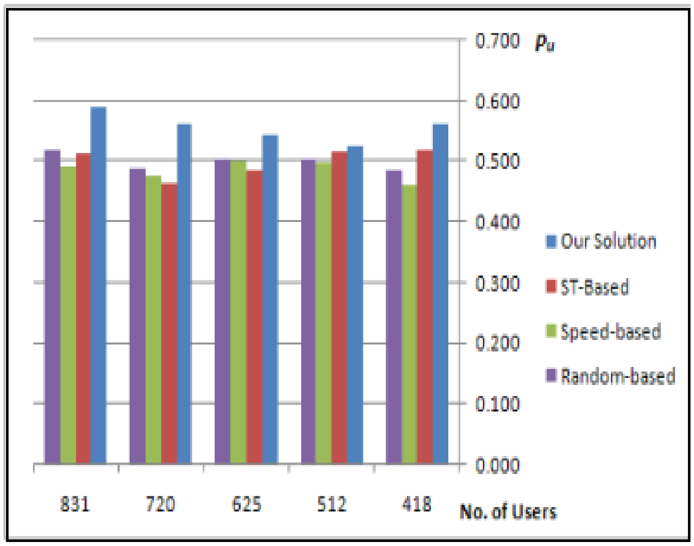

Figure 6. P_u values for all

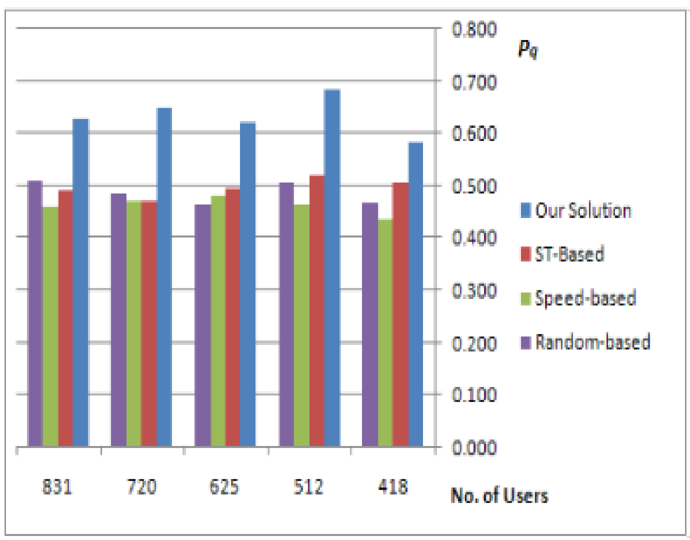

Figure 7. P_q values for all algorithms

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 make 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.

No. of Users	Our solution	MSS selection	Random selection	ST selection
418	0.549	0.560	0.517	0.488
512	0.499	0.518	0.514	0.479
625	0.521	0.546	0.555	0.477
720	0.521	0.592	0.524	0.538
831	0.5	0.528	0.511	0.477

Table 3. P_o values in all algorithms

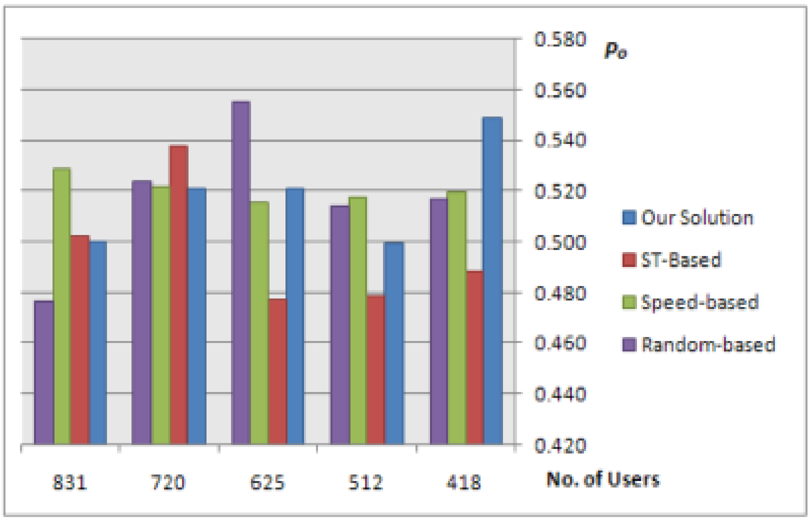

Figure 8. P_o values for all algorithms

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