Fuzzy Logic Based Call Admission Control for Next Generation Wireless Networks

Olabisi E. Falowo and H. Anthony Chan
Department of Electrical Engineering, University of Cape Town, South Africa
Email: bisi@crg.ee.uct.ac.za; achan@ebe.uct.ac.za

Abstract— Different radio access technologies (RATs) such as UMTS, WiMax, WLAN, etc, will coexist in next generation wireless networks (NGWN). This coexistence of RATs necessitates joint radio resource management (JRRM) for efficient radio resource utilization and improved users' satisfaction. Admitting a call into the most appropriate RAT based on many selection criteria is major challenge in NGWN. This paper focuses on joint call admission control (JCAC) algorithm which is one of the JRRM algorithms. We propose a Fuzzy Logic based JCAC scheme for NGWN. The JCAC scheme consists of local CAC algorithms and a RAT selection algorithm. Each RAT has a local CAC algorithm which select the most appropriate cell for an incoming call, and determine whether the call can be admitted into the cell or not. A RAT selection algorithm then selects the most appropriate RAT for the incoming call among the RATs whose selected cell meets the local call admission condition. The proposed JCAC scheme is illustrated using two local CAC criteria and five RAT selection criteria.

Index Terms—Next generation wireless network, call admission control, Fuzzy Logic, radio access network, mobile terminal.

I. Introduction

Next Generation Wireless Networks (NGWNs) will combine existing and new technologies to provide high bandwidth anytime, anywhere for multimedia services. Mobile users will be able to communicate through different radio access technologies (RAT) and roam from one RAT to another by using multimode mobile terminals (MTs) [1, 2].

These RATs have different features in coverage area, service cost, maximum data rate, security levels, etc, they offer to users. Therefore, admitting a user into the most appropriate RAT based of many selection criteria is a major challenge in NGWN.

Call admission control (CAC) algorithm is one of the RRM algorithms. It is used to decide whether or not to accept a new or handoff call into a network without violating the service commitment made to the already admitted calls. The objective of a CAC algorithm is to ensure that QoS requirements of all admitted calls are satisfied while still making the best use of the available radio resources.

The traditional CAC for homogeneous networks only determines whether a user may be admitted into the networks or not. In heterogeneous networks, however, the CAC is additionally responsible for deciding which radio access network is best suited to accommodate the incoming user [3, 4].

Several CAC algorithms have been developed for homogenous wireless networks in the literature [5-7]. However, these homogeneous algorithms do not provide a single solution to address the heterogeneous architectures which characterize next generation wireless networks [2].

In the literature, some algorithms have been proposed for call admission control in heterogeneous wireless networks. Initial RAT selection algorithm is proposed in [8]. Vertical handover RAT selection algorithm is proposed in [9]. Initial network access and handover control algorithm is proposed in [4]. Most of the network selection algorithms proposed for heterogeneous wireless networks are based on policy [8], predicted information [10], Fuzzy logic [11], Fuzzy Multiple Attribute Decision Making (MADM) technique [12], or Genetic algorithm [2].

The algorithm proposed in [10] uses prediction of user mobility pattern and call holding time for selecting an access network which maximizes the expected value of user satisfaction in heterogeneous network environment. The choice of optimal RAT for an incoming call is based on the predicted mobility pattern and call holding time of the call. The algorithms did not consider other criteria such as service cost, received signal strength, etc, in making admission decision. Moreover, the efficiency of the scheme depends on the accuracy of predicted information

Chan et al [12] proposes a segment (RAT) selection algorithm based on fuzzy multiple objective decision making model. The main purpose of the segment selection algorithm is to select a segment for a particular service which can satisfy the following objectives; low cost, good signal strength, optimum bandwidth, low network latency, high link availability, long battery life, while taking into account the preferred segment of the user.

The algorithm operates in two stages. In the first stage, fuzzification procedure and weighting of the criteria are performed. The former involves the evaluation and comparison of the available segments, whereas the latter is used to evaluate the importance of each criteria based on the instructions received from the network provider and user. In the second stage, weights are applied to each criterion. A decision function (D) is then obtained, which can simultaneously satisfy all the decision objectives. One decision function is calculated

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for each segment. The chosen segment is the segment with the maximum membership value of D.

The segment selection algorithm proposed in [12] did consider a multi-cell RAT scenario, where some of the available RATs have many cells.

Giupponi *et al* [13] propose a Fuzzy Neutral joint radio resource management algorithm for heterogeneous wireless network. In the proposed algorithm, they consider a multi-cell scenario which comprises four UMTS based stations, two GERAN base stations, and one WLAN Access Point. The algorithm operates in two steps in order to select the most appropriate RAT and cell for an incoming call.

Firstly, combinations of any three cells (i.e. one per RAT) are selected. A fuzzy controller is then applied to all the possible combinations of cells (8 combinations in this case), and the best combination is selected. Afterwards, a Fuzzy Neutral JRRM algorithm is applied to the best combination of three cells in order to select the most appropriate RAT for the incoming call.

A major problem with this approach is scalability. For instance, if four RATs each having three cells are considered, the Fuzzy logic controller will have be applied to 81 combinations of cells. RAT selection algorithms should be able to accommodate increase in capacity or size of the heterogeneous wireless network such as integration of a new access network.

In this paper, we propose a scalable fuzzy based joint call admission control scheme for NGWN. Similar to [13], the proposed scheme operates in two stages. As shown in Fig. 1, the first stage consists of cell selection and local call admission decision.

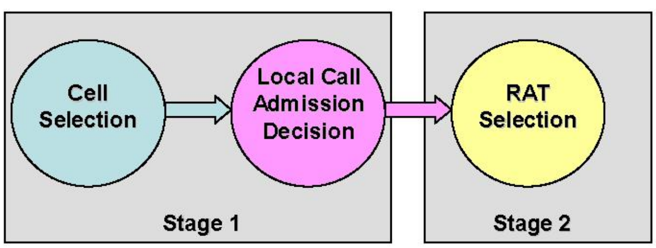

Fig. 1. Block diagram of the proposed Joint CAC Scheme.

The second stage consists of RAT selection for an incoming call. However, different from [13], a fuzzy based local CAC algorithm in each RAT selects the most appropriate cell for an incoming call in the RAT, and determines if the call can be accepted into the selected cell (i.e. local CAC algorithm makes call admission decisions).

The cell selected by the local CAC algorithm in each RAT is only considered for further selection by the RAT selection algorithm if local admission conditions are met. One major advantage of this approach is high scalability. Another advantage is high execution speed because the local CAC algorithm in each of the RATs operates in parallel.

In the second stage, a Fuzzy MADM based RAT selection algorithm selects the most appropriate RAT among the RATs whose selected cell meets the local call admission condition.

The rest of this paper is organized as follows. Section 2 describes the proposed fuzzy based call admission control scheme. In section 3, the fuzzy based local CAC is presented. Section 4 describes the RAT selection algorithm with fuzzy MADM. The joint CAC procedure is illustrated in section 5.

II. PROPOSED JOINT CAC ALGORITHMS

The proposed CAC scheme consists of local CAC algorithms and a RAT selection algorithm. As shown in Fig. 2, a fuzzy based local CAC algorithm is located in each of the RATs. It selects the most appropriate cell to admit an incoming call based on the received signal strength in the cell. The cell where the mobile terminal has the highest signal strength is selected in each RAT. The local CAC algorithm then determines if the incoming call can be admitted into the selected cell. The Local CAC algorithm is executed when a new call, horizontal handoff call, or vertical handoff call arrives into a particular RAT.

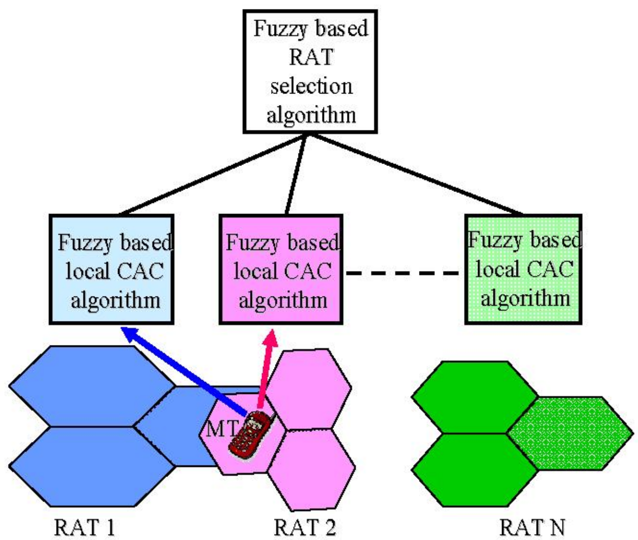

Fig. 2. Proposed joint CAC scheme.

After the local call admission has been made in each RAT, the RAT selection algorithm selects the most appropriate RAT among the RATs whose selected cell meets the local call admission decision. The criteria that can be used to select the most appropriate RAT by the RAT selection algorithm are many and are summarized in Table 1. All the criteria cannot be used simultaneously and there are tradeoffs among them.

Table 1. RAT Selection Criteria.

Criteria	User's Preferences	Operator's preferences	Other criteria
1	Least service cost	Uniform load distribution	Application requirements
2	Best QoS	Revenue maximization	RAT residual capacity
3	Widest coverage	Power consumption optimization	Mobile terminal capability
4	Highest security	Handoff call dropping minimization	
5	Least battery power consumption		

Two scenarios can be considered for call admission: when there is no seamless vertical handover among the RATs and when there is seamless vertical handover among all or some of the RATs.

i) There is no seamless vertical handover among the available RATs: In this scenario, the RAT selection algorithm is executed only when a new call or vertical handoff call arrives. Vertical handover takes place only when horizontal handover is not possible due to lack of coverage (poor signal strength) or lack of radio resources in the current RAT.

ii) There is seamless vertical handover among all or some of the available RATs: In this scenario, RAT selection algorithm is executed when a new call, horizontal handoff call, or vertical handoff call arrives. Horizontal handover and vertical handover are treated alike. When an MT in a particular RAT is moving from one cell to another, all the target cells in the available RATs will be considered. A new cell can be selected from the current RAT or from a different RAT.

III. Fuzzy Based Local CAC Algorithm

Each of the local CAC uses a fuzzy logic controller. As shown in Fig. 3, the fuzzy logic controller consists of fuzzifier, inference engine, fuzzy rule base, and a defuzzifier.

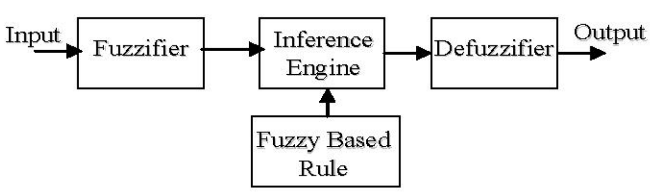

Fig. 3. Fuzzy Logic Controller of the proposed join CAC.

The fuzzifier translates the input numerical measurements to the corresponding linguistic values of the fuzzy sets in the input universe discourse. The membership functions used are triangular and trapezoidal membership functions as show in Fig. 4. The fuzzy variables used are signal strength (SS) received by the multimode MT from the base station (or access point) in each cell, and the current load (L) in the cell. Four member functions are used for current load in the selected cell whereas two membership functions are used for received signal strength in the cell. The output linguistic parameter is the local admittance decision (LAD), and it has three membership functions. The term sets of SS, L, and LAD are defined respectively as:

T(SS) = {Low, Medium, High} = {L, M, H}
T(L) ={Very Low, Low, High, Very High}={VL, L, H, VH}
T(LAD)={Reject, Weak Accept, Accept} = {R, WA, A}

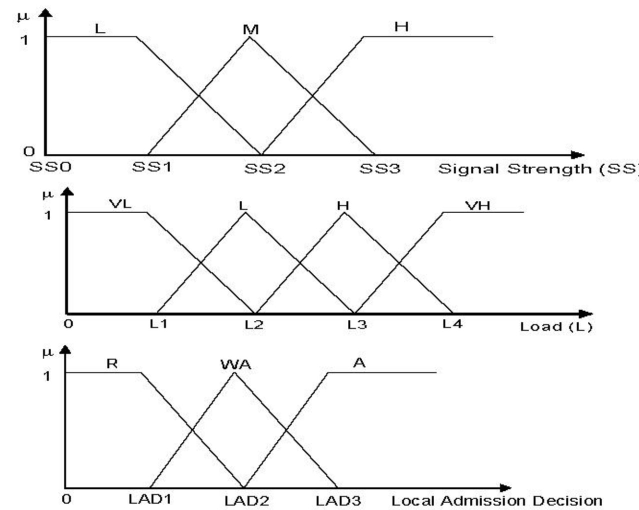

Fig. 4. Fuzzy membership function definition.

The inference engine makes use of some predefined fuzzy rules to determine, for each RAT, whether the incoming call can be admitted into the selected cell or not. The predefine rules are a series of "If then" rule and are show in Table 2.

Table 2. Fuzzy rules for the Local CAC algorithm.

Rule	L	SS	LAD
0	VL	L	R
1	VL	M	A
2	VL	H	A
3	L	L	R
4	L	M	A
5	L	H	A
6	H	L	R
7	H	M	WA
8	H	H	WA
9	VH	L	R
10	VH	M	R
11	VH	H	R

Defuzzification involves the conversion of the fuzzy outputs into crisp output (LAD*). There are many defuzzification methods such as the weighted average method, centroid method, etc. The weighted average defuzzification method is used to illustrate the proposed joint CAC (1).

$$LAD^* = \frac{\sum [\mu(LAD) * LAD]}{\sum \mu(LAD)} \tag{1}$$

IV. RAT SELECTION ALGORITHM WITH FUZZY MADM

The RAT selection problem is formulated as a fuzzy MADM problem. Fuzzy logic is used to represent the imprecise information of some selection criteria such as service cost. Generally, fuzzy MADM consists of two stages [14]. In the first stage, fuzzy data are converted into real data. In the second stage, classical MADM is used to determine the ranking order of the candidate networks.

There are many classical MADM methods such as SAW (Simple Additive Weighting), TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), AHP (Analytical Hierarchical Process), etc. In this paper, the proposed JCAC is illustrated using SAW method. In SAW, if there are M alternative networks (RATs) and N decision criteria, the best alternative is the one that satisfies the following expression.

$$A^*_{SAW} = \arg\max_{i \in M} \sum_{j=1}^{N} w_j r_{ij}, \quad for\, i = 1, 2, ..., M. \quad (2)$$

Where A_{SAW}^* is the SAW score of the best alternative network, r_{ij} is the actual value of the i-th alternative in terms of the j-th criterion, and W_j is the normalized weight of importance of the j-th criterion. The weights show the relative importance of the criteria to users [15]. For example, if a criterion A_1 has relative importance 1 and the relative importance of a criterion A_2 is 5, then A_2 is considered to be five times more important than A_1.

The relative importance can be assigned with linguistic attributes (e.g., 1 means equal importance, 3 weak importance of one over another, 5 essential or strong importance, 7 very strong or demonstrated importance and 9 absolute importance) which are easier for the human expert to specify.

V. ILLUSTRATION THE CALL ADMISSION PROCEDURE

We consider a heterogeneous wireless network which consists of three RATs; UMTS (R_1), GERAN (R_2), and WLAN (R_3). UMTS has 3 base stations (A_U, B_U, C_U), GERAN has 3 base stations (A_G, B_G, C_G), and WLAN has one access point (A_W) as shown in Fig. 5.

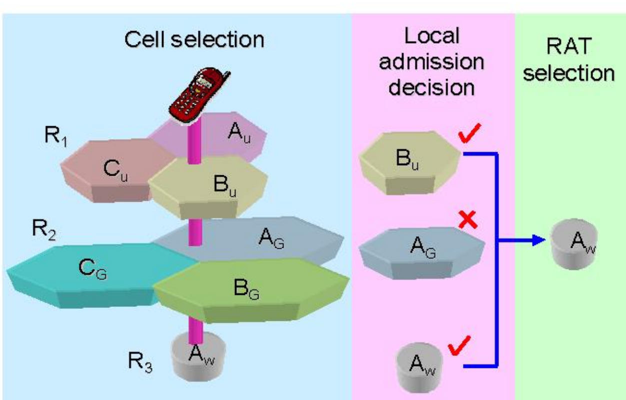

Fig. 5. Cell and RAT selection for an incoming call.

When a new call arrives in the heterogeneous wireless network, the local CAC in R_1, R_2, and R_3 selects cell B_U, A_G, and A_W respectively for the incoming call based on the highest received signal strength.

The local CAC algorithm in each RAT then determines if the incoming call can be admitted into the selected cell based on the value of the received signal strength and current load in the cell. In Fig. 4, given that the values of SS0, SS1, SS2, SS3, L1, L2, L3, L4, LAD1, LAD2, and LAD3 are -78 dBm, -75 dBm, -72 dBm, -69 dBm, -66 dBm, 20%, 40%, 60%, 80%, 0.25, 0.5, 0.75 respectively. Given that the received signal strength and the current load (SS, L) in the selected cell of UMTS, GPRS, and WLAN are (-69 dBm, 30%), (-73.5 dBm, 80%), (-72 dBm, 50%) respectively. The values of LAD* for UMTS, GPRS, and WLAN are calculated using Table 2 and equation 1. These values are show in Fig. 6. RT is the rejection threshold for the local CAC algorithm in each RAT.

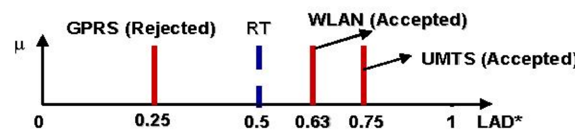

Fig. 6. Local CAC algorithm rejection threshold.

As show in Fig. 5 and Fig. 6, the incoming call cannot be accepted into the selected cell of R_2 based on the local call admission decision. However, it can be admitted into the selected cells of R_1 and R_3. Therefore, only R_1 and R_3 are considered for further selection.

The RAT selection algorithm then selects one of the two remaining RATs (R_1 or R_3) based on some selection criteria. The selection criteria considered in this example are data rate (A_1), service cost (A_2), coverage (A_3), security (A_4), battery power consumption (A_5).

The objective is to select a RAT with a high data rate, low service cost, wide coverage, high security, and low battery power consumption. Weight are attached to each criterion by the user is shown below.

W* = [9, 9, 1, 3, 1]

The normalized weight, W=[0.391, 0.391, 0.043, 0.130, 0.043]

The attributes of R_1 and R_2 are presented in the following decision matrix (D).

$$D = \begin{array}{c} \\ R_1 \\ R_3 \end{array} \begin{array}{c} \begin{array}{ccccc} A_1 & A_2 & A_3 & A_4 & A_5 \end{array} \\ \begin{bmatrix} 2 & high & 10{,}000 & high & 1 \\ 11 & low & 100 & low & 0.5 \end{bmatrix} \end{array}$$

The linguistic terms used in the decision matrix, D, are converted to crisp numbers using the conversion scale shown Fig. 7 [14, 16]. The five fuzzy numbers shown in Fig. 7 are converted to 0.091, 0.283, 0.5, 0.717, and 0.909 respectively.

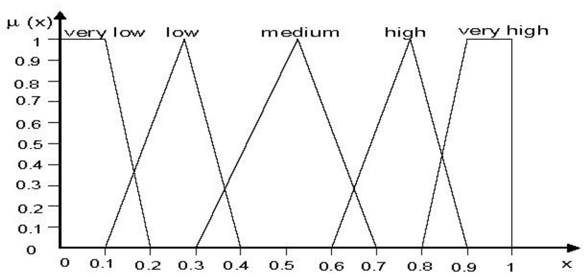

Fig. 7. Linguistic terms to fuzzy number conversion scale.

The following is the resulting matrix after converting the fuzzy numbers into crisp values.

$$D = \begin{array}{c} \\ R_1 \\ R_3 \end{array} \begin{array}{c} \begin{array}{ccccc} A_1 & A_2 & A_3 & A_4 & A_5 \end{array} \\ \begin{bmatrix} 2 & 0.717 & 10{,}000 & 0.717 & 1 \\ 11 & 0.283 & 100 & 0.283 & 0.5 \end{bmatrix} \end{array}$$

There is need to normalize the elements in the decision matrix D since they have different dimensions. Usually, there are benefit criteria and cost criteria. In this case, A_1, A_3, and A_4 are benefit criteria whereas A_2 and A_5 are cost criteria. The normalized value b_{ij} of the normalized decision matrix D' is calculated using the following equations.

$$b_{ij} = \begin{cases} \dfrac{a_{ij}}{\max\{a_{ij} \mid i = 1, 2, ..., m\}}, & for\ benefit\ criterion\ A_j \\ \dfrac{\min\{a_{ij} \mid i = 1, 2, ..., m\}}{a_{ij}}, & for\ cost\ criterion\ A_j \end{cases} \tag{3}$$

$$D' = \begin{array}{c} \\ R_1 \\ R_3 \end{array} \begin{array}{c} \begin{array}{ccccc} A_1 & A_2 & A_3 & A_4 & A_5 \end{array} \\ \begin{bmatrix} 0.181 & 0.395 & 1 & 1 & 0.5 \\ 1 & 1 & 0.01 & 0.395 & 1 \end{bmatrix} \end{array}$$

The ranking values of R_1 and R_3 are obtained using (2).

R1= 0.4197 and R3 = 0.8768

Thus the ranking result of the alternative network is $R_3 > R_1$, and therefore R_3 is selected.

VI. CONCLUSION

In this paper, we proposed a fuzzy based joint CAC scheme for NGWNs. The proposed joint CAC operates in three steps: cell selection, local call admission decision, and RAT selection. Cell selection and local call admission decision are performed by the local CAC algorithm in each RAT whereas RAT selection is performed by the RAT selection algorithm. We illustrate the fuzzy based joint CAC procedure using two cell selection criteria: received signal strength and current load in each cell. RAT selection is based on five criteria: data rate, service cost, coverage, security, and battery power consumption. Scalability is the major advantage of the proposed joint CAC scheme.

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