Energy-friendly Network Selection in Heterogeneous Wireless Networks

Juan Fan , Sihai Zhang , Wuyang Zhou

Wireless Information Network Lab.,
Department of Electronic Engineering and Information Science,
University of Science and Technology of China, Hefei, Anhui, China 230027
Email: rosa144@mail.ustc.edu.cn,shzhang@ustc.edu.cn, wyzhou@ustc.edu.cn

***Abstract*—Mobile terminals in heterogeneous wireless networks continuously undergo network selection within the initial access process and handover process. In order for a mobile terminal to be connected to a network in the best possible way in terms of QoS performance and energy consumption, this paper presents a novel method that takes into account user preferences, network conditions, QoS and energy consumption requirements in order to select the optimal network which achieves the best balance between performance and energy consumption. The proposed network selection method incorporates the use of fuzzy logic because of the available sources of information from different radio access technology (RAT) are qualitatively interpreted and heterogeneous in nature, and adopts different energy consumption metrics for real-time and non-real-time applications. Finally, simulations confirm our scheme's suitability and effectiveness.**

Keywords: heterogeneous wireless networks, access network selection, energy efficient, fuzzy logic

I. Introduction

Heterogeneous wireless networks include coexistence of current wireless technologies such as 2G/3G cellular, satellite, Bluetooth, LTE, 802.11, 802.16, 802.20. With the availability of multi-mode mobile terminals capable of accessing different technologies, the introduction of heterogeneous wireless access environment raises a new challenge for the study of radio resource management. In particular, selecting a radio access network for users in terms of QoS performance and energy consumption, has become a hot topic in radio resource management of heterogeneous networks.

Considering the problem of access network selection, the concept of ABC (always best connected) allows a mobile terminal connectivity to applications and access technologies that best suit the user's needs[1]. However, how to define "the best" is not much accurate because it depends on many different aspects, such as user preferences, terminal capabilities, service QoS, network coverage, network load, price, energy consumption and many other factors. The decision making of access network considering energy consumption has been considered[2]-[6]. Liu et al. [3] propose a cost-function based network selection scheme, and achieve a significant reduction of energy consumption through the reduction of network scanning operations that occur when the network selection process starts. Apart from investigation of mechanisms reducing network scanning operations, most research focus on selecting the most energy efficient network or achieving the best balance between performance and energy consumption.

Therefore, in this paper, we propose a novel network selection method based on fuzzy logic[7] that takes into account both network conditions and user preferences as well as QoS requirements in order to get a fuzzy selected decision, and then combines the fuzzy selected decision and energy consumption together to select the network that achieves the best balance between performance and energy consumption. The fuzzy logic method has been formerly applied to network selected problems in heterogeneous wireless environments [8][9][10].

The innovation of this paper can be summarized as follows: first of all, the scheme we proposed is distributed, and the mobile terminal selects the access network, while the selected network just do the admission control. Secondly, the decision made by mobile terminal adopts the method of fuzzy logic and different energy consumption metrics for real-time and non-real-time applications to achieve the intelligent access network selection.

The remainder of this paper is organized as follows: Section 2 presents the proposed network selection architecture, and the details of the proposed scheme are described in Section 3. Section 4 gives simulation results and related discussions. Section 5 concludes this research.

II. Architecture

In this paper, we present a distributed access network selection scheme which is terminal-controlled and network-assisted. The mobile terminal does the access selection process, and after that the selected network does the admission control process. This scheme can be implemented in current networks because of no need of central entity. The architecture of the scheme we proposed is shown in Fig.1.

When initial access or handover occurs, the access selection process in mobile terminal is triggered. Therefore, the mobile terminal can detect the set of available networks by scanning the wireless signals. At the same time, the mobile terminal can also acquires the condition indicator of each available network which is assumed to broadcast periodically.

Then, after collecting the information for decision, the mobile terminal inputs the heterogeneous parameters to the fuzzy logic unit to get an output of fuzzy selected decision.

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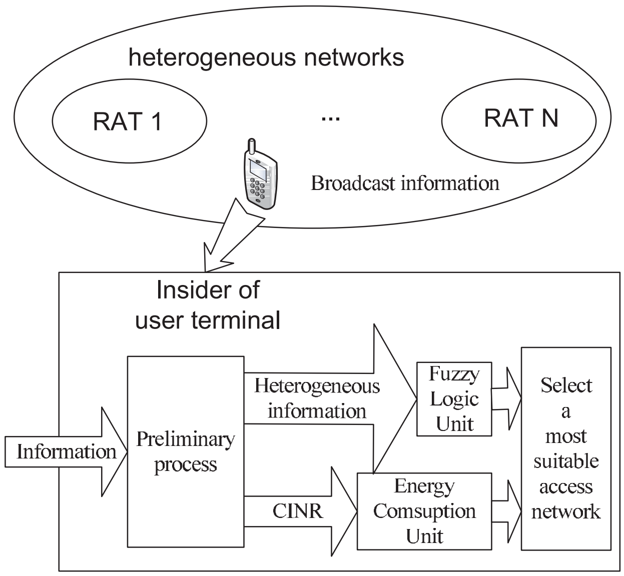


Fig. 1. Architecture of the scheme we proposed.

In the mean time, the mobile terminal estimates the energy consumption of each available network based on the CINR. After that, the mobile terminal combines fuzzy selected decision and energy consumption of each available network to select the most suitable network. At this point, the mobile terminal completes the selection process.

The mobile terminal sends an access request message to the selected network, along with the user's QoS requirement (service type, bandwidth requirement, etc). The selected network starts the process of admission. If the user's QoS could be satisfied, this request will be accepted. Otherwise, the network will reply a reject message with the reason. And then, the process of admission is over.

When the mobile terminal receives the accept message from the selected network, it means that the whole access selection-admission process is over. Otherwise, the mobile terminal should consider the reason of failure, and start the access selection-admission process again.

III. Energy-friendly network selection

Since we focus on the distributed network selection process, the mobile terminal continuously collects available access network characteristics. Such characteristics may include monetary cost, available bandwidth, reliability, etc. This information in combination with relevant energy consumption data is utilized in the management of radio interfaces, in triggering the handover process as well as in the selection of the best access network among available ones.

In order to select the network that achieves the best balance between QoS performance and energy consumption, the mobile terminal must identify the relevant decision criteria. Without loss of generality, in the rest of the paper, we will consider resource available information as an example of network performance and mobile speed as an example of mobile terminal performance. In order to aggregate different criteria under a network ranking we propose the use of fuzzy logic unit. Furthermore, the selection method has to take into account energy consumption, which implement in energy consumption unit.

The details of the scheme we proposed is as follows.

A. Fuzzy Logic Unit

The fuzzy logic method we takes presented in literatures[7]. Inside of fuzzy logic unit, fuzzy logic control (FLC) implements the fuzzifier, the inference engine, and the defuzzifier. The whole fuzzy logic unit works in two phases. The first one is offline training, through which the FLC parameters are tuning. However, investigation of mechanisms tuning parameters is out of the scope of this paper. The second phase is online process, during which the FLC based on the selected input linguistic variables, generates the corresponding output linguistic variables, and then fuzzy selected decision is made.

Let N be the number of RATs scanned in the mobile terminal. For the simplify, we take two kinds heterogeneous parameters for example, and the structure of FLC is shown in Fig.2.

1) Fuzzy Logic Controller: The FLC can be represented by the five-layered structure described in Fig.2.

The first layer nodes are input nodes. We consider N+1 input linguistic variables here: resource available (RA) of the available RATs and mobile speed of the terminal.

The second layer nodes execute the fuzzification operation. They calculate the degree of membership for the input received by the input nodes to the particular fuzzy set associated with the second layer node, which is defined by a membership function. The term sets defined for each input linguistic variable are as follows.

- T($RATi\_RA$) = T$\{low, medium, high\}$,
- T(MT_UPI) = T$\{low, high\}$,

where $i = 1, 2...N$. So that the second layer consists of $3N + 2$ nodes. In case of Gaussian membership functions, the degree of membership μ_{ij} for the input variable i, the fuzzy set j is calculated by

$$\mu_{ij}(x_i) = \exp(-\frac{(x_i - m_{ij})^2}{2\sigma_{ij}^2}), \tag{1}$$

where x_i ($i = 1, 2, ...N + 1$) is one of the input linguistic variables, m_{ij} and σ_{ij} ($i = 1, 2, ...N + 1$; $j = 1, 2$ or $j = 1, 2, 3$) are mean and variance of the related Gaussian membership function at the second layer.

The third layer nodes calculate the degree of membership of the precondition of the fuzzy logic rule corresponding to the specific node by means of the AND operator, so that the rule node takes the minimum among the received inputs from the second layer. Considering the term sets defined in the second layer, the number of the third layer nodes is $3^N \cdot 2$. Therefore, the degree of the third layer node is calculated by

$$a_{j_1 j_2 ... j_{N+1}} = \min(\mu_{1j_1}, \mu_{2j_2}, ..., \mu_{N+1 j_{N+1}}), \tag{2}$$

The fourth layer nodes calculate the degree of membership of the consequence of the fuzzy logic rule. The number of this layer nodes depends on the output linguistic variable of

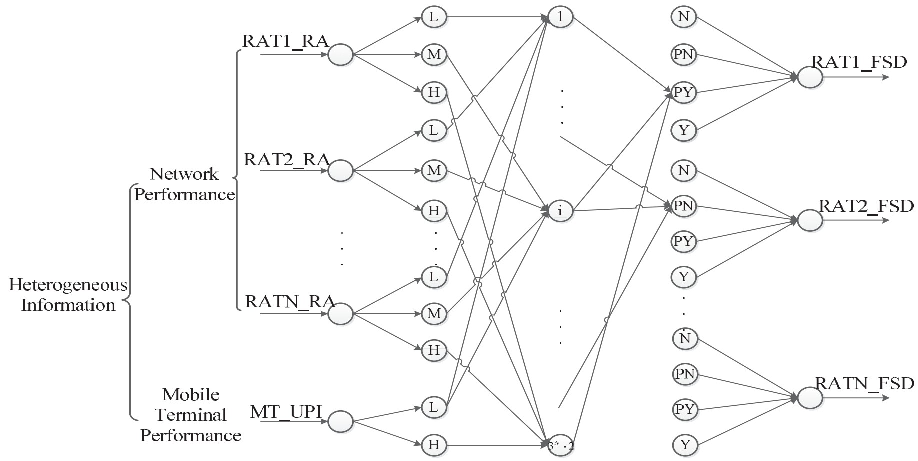


Fig. 2. The five-layer structure of fuzzy logic controller.

the fifth layer. The term sets defined for each output linguistic variable are as follows.

- T($RATj\_FSD$) = T$\{N(not), PN(probabily\, not), PY(probabily\, yes), Y(yes)\}$,

where $j = 1, 2, ...N$. FSD denotes fuzzy selected decision. So that, the fourth layer consists of $4N$ nodes.

The fourth layer nodes sum the degree of membership of the third layer nodes, which related to the specific fourth layer node as a consequence of the fuzzy logic rule. So,

$$b_i = \min(\sum a_{j_1 j_2 \ldots j_{N+1}}, 1), \tag{3}$$

where $a_{j_1 j_2 \ldots j_{N+1}}$ denote the third layer nodes that related to specific node i in fourth layer.

The fifth layer nodes finally perform the defuzzication process, and compute the output of fuzzy selected decision by the center of area method.

$$FSD_i = RATi\_FSD = \frac{\sum_{j \in T_i} m_j \sigma_j b_j}{\sum_{j \in T_i} \sigma_j \ b_j}, i = 1, 2, ...N \tag{4}$$

m_j and σ_j ($j = 1, 2, ...N$) are mean and variance of the related Gaussian membership function at the fourth layer. T_i is the set of the fourth layer nodes that related to node i of the fifth layer.

2) Fuzzy Selected Decision: After the FLC process, we get fuzzy selected decision FSD_i, ($i = 1, 2, ...N$), and $0 \leq FSD_i \leq 1$.

B. Energy Consumption Unit

The energy consumption unit estimates the data rate and power consumption of each available access network from the CINR of each. In the proposed scheme, the values are previously measured and written into the memory table in the mobile terminal. The metric of energy consumption is not common in all QoS classes of applications. The main divide is between non-real-time applications and real-time applications since in the former case energy consumption does not equal power consumption[5]. In non-real-time application, the terminal needs to select a RAT with lower energy consumption for fixed size data reception. It is noteworthy that the energy consumption does not equal the power consumption. Therefore, in the case of non real-time application the relevant energy consumption metric can be defined as the power consumption per bit of transfer. Conversely, in the case of real-time applications the energy consumption must be compared for communications of a specific fixed time, therefore in this case the metric of energy consumption equals the power consumption for communications in the access network.

Since N be the number of RATs scanned in the mobile terminal, we let $b_i(CINR_i)$ and $P_i(CINR_i)$ denote the bit rate and power consumption of the RAT i, respectively. Then the metric of energy consumption $EMetric_i$ is decided with the application type and calculated as follows:

For non-real-time applications:

$$EMetric_i = \frac{P_i(CINR_i)}{b_i(CINR_i)}, i = 1, 2, ...N \tag{5}$$

For real-time applications:

$$EMetric_i = P_i(CINR_i), i = 1, 2, ...N \tag{6}$$

C. Decision Making

In this step, we already have the fuzzy selected decision FSD_i, ($i = 1, 2, ...N$) and the metric of energy consumption $EMetric_i$, ($i = 1, 2, ...N$). By combining these parameters, we define a utility function U_i, ($i = 1, 2, ...N$) as follows:

$$U_i = \alpha \cdot \frac{FSD_i}{FSD_{max}} + \beta \cdot \frac{EMetric_{min}}{EMetric_i} \tag{7}$$

α, β denote the weight of two different kinds of input, respectively. FSD_{max} denote the max value of FSD_i, ($i = 1, 2, ...N$) and $EMetric_{min}$ denote the min value of $EMetric_i$, ($i = 1, 2, ...N$). We fix the sum of the two weights equals 1.0 ($\alpha + \beta = 1.0$), then we can bound the utility U_i by $[0, 1]$.

Therefore, the mobile terminal can select the most suitable access network $\hat{i}$ as follows:

$$\hat{i} = \underset{i}{\operatorname{argmax}}\, U_i \tag{8}$$

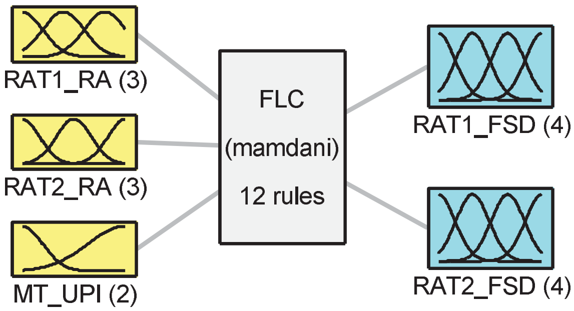


Fig. 3. System FLC: 3 inputs, 2 outputs, 12 rules.

Then the mobile terminal continues the following steps of our scheme described in section 2.

IV. Simulations and Discussion

In this paper, we define simulation scenario of heterogeneous wireless networks HWN = $\{RAT1, RAT2\}$. We choose RAT1 as a wireless wide area network (WWAN) capable of supporting high speed mobile terminals, such as IEEE 802.20 access technology, and RAT2 as a metropolitan area network (WMAN) capable of achieving high data rate, such as IEEE 802.16.

According to Part 3, the input of FLC are RA and UPI that described in detail as follow.

- RAT_RA(100%): Resource available that the mobile terminal can get from broadcast message.
- MT_UPI(m/s): User preference indicator, and we use the speed of the mobile terminal here.

Based on access technology, we can define the fuzzy logic rules in Table.I, whereas the membership functions after the offline training are depicted in Fig.3.

TABLE I
Fuzzy Logic Rules Table

IF			THEN	
RAT1_RA	RAT2_RA	MT_UPI	RAT1_FSD	RAT2_FSD
L	L	L	PN	PN
M	L	L	PY	PN
H	L	L	Y	PN
L	M	L	PN	PY
M	M	L	PY	PY
H	M	L	Y	PY
L	H	L	PN	Y
M	H	L	PY	Y
H	H	L	Y	Y
L	L,M,H	H	PN	N
M	L,M,H	H	PY	N
H	L,M,H	H	Y	N

The bit rate and power consumption for each CINR of both RATs are listed in Table.II[5]. From Table.II, we can see that RAT1 is capable of achieving a moderate data rate even in the lower CINR region and lower power consumption, and RAT2 is capable of achieving a higher data rate and power consumption within a higher CINR region.

In order to test the impact of weight, three different policies are defined and evaluated. Their configurations are presented in Table.III.

TABLE II
Data Rate and Power Consumption Table

CINR (dB)	RAT1		RAT2	
	Data Rate (kbps)	Power Consumption (mW)	Data Rate (kbps)	Power Consumption (mW)
[Min,-15)	0.0	250	0.0	450
[-15,-10)	38.4	300	0.0	450
[-10,-5)	76.8	350	64.0	500
[-5,0)	204.8	400	128.0	550
[0,5)	921.6	450	512.0	600
[5,10)	1843.0	500	1024.0	650
[10,15)	2400.0	550	4096.0	700
[15,20)	2400.0	550	8192.0	750
[20,Max)	2400.0	550	12288.0	800

TABLE III
Simulated Policies

Policies	α	β
PD ($Performance\ Domination$)	0.8	0.2
PE ($both\ of\ Performance\ and\ Energy$)	0.5	0.5
ED ($Energy\ Domination$)	0.2	0.8

The simulation results presented in the Fig.4 compare different input parameters, when different policies are simulated.

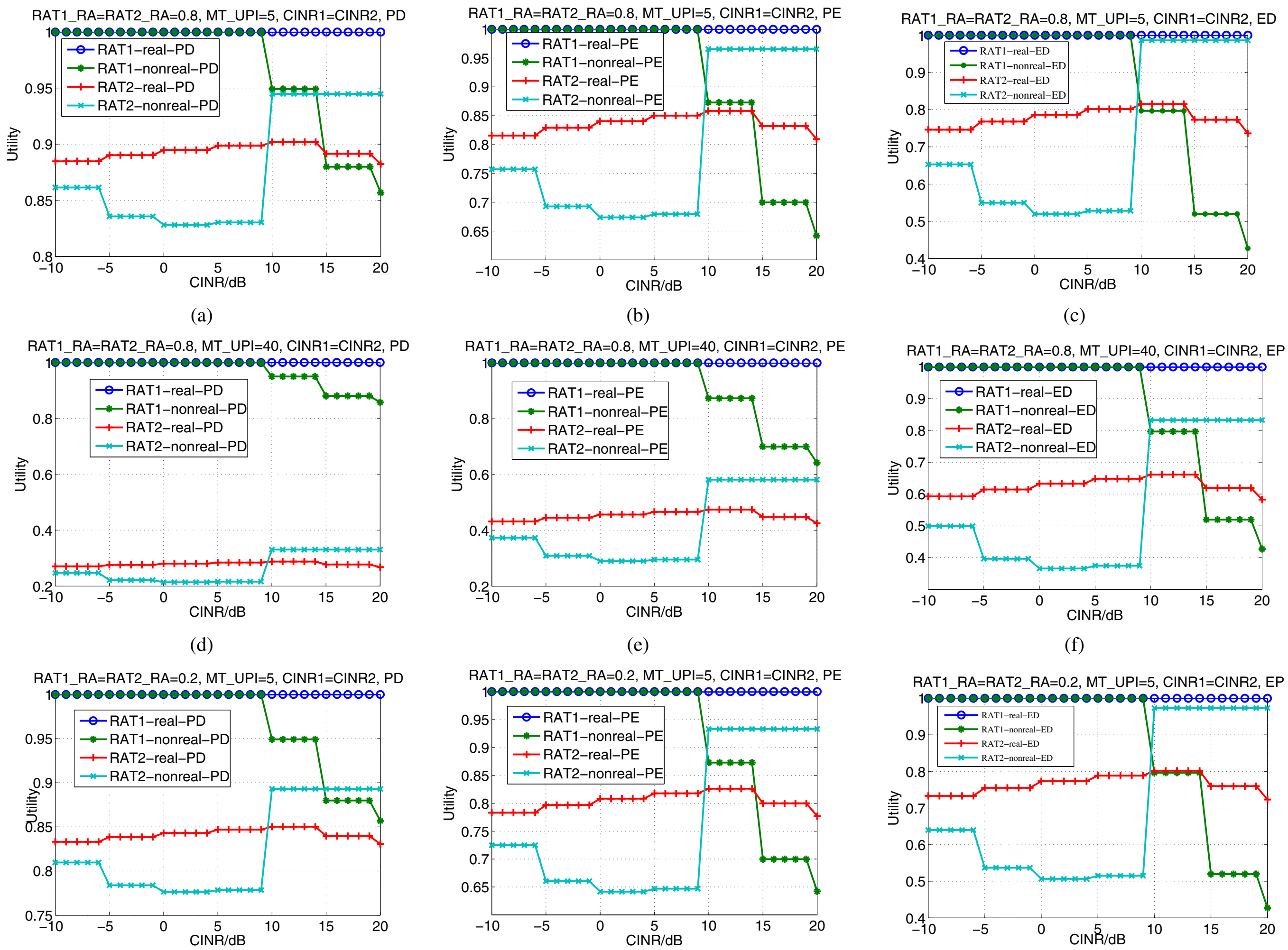
Fig.4 shows that in real-time application, RAT1 is always the best network for terminal, which assistant with the Table.II. In real-time application, RAT2 always consumes much more energy than RAT1. However, in the non-real-time application, when CINR is more than 10dB, RAT1 would consume more energy than RAT2. It assistant with the energy consumption unit described in section 3.

From Fig.4(d)(e)(f), we can see that when mobile speed of terminal is high, the terminal tend to choose RAT1 unless resource of RAT1 is not enough, which assistant with the fact that RAT1 be as a wireless wide area network (WWAN) capable of supporting high speed mobile terminals.

Simulation results also shows that with the increment of CINR, the terminal would change its choice earlier when using ED policy before PD or PE policy. The reason is that ED policy concerns energy consumption more than the other two policy, and CINR effects energy consumption.

V. Conclusion

Multi-mode mobile terminals roaming freely across different wireless systems continuously undergo network selection. In such dynamic environments, the achievement of the best balance between QoS performance and energy efficiency is a crucial issue. This paper proposes a scheme that takes into account user preferences, network conditions and energy consumption requirements in order to guarantee the selection of the optimal network. Furthermore, the proposed method incorporates the use of fuzzy logic to handle the heterogeneous information, and energy consumption measurement is performed according to two different metrics corresponding to the energy consumption characteristics of real-time and non-real-time applications. The performed simulations, which were conducted in order to demonstrate, validate and observe how the proposed method would work, confirm that the proposed method achieves a balance between performance and energy



(a) (b) (c) (d) (e) (f) (g) (h) (i)

Fig. 4. Simulation results.

consumption. As future work, we will consider more complex scenarios and evaluate the effects of more parameters of decision-making process on the performance of the access selection scheme.

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