An NN-Based Access Network Selection Algorithm for Heterogeneous Networks

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***Abstract*—Next generation wireless network is expected to integrate multiple wireless technologies and provide mobile users with communication connectivity of different QoS requirements. However, the heterogeneity of access networks and the variety of user application requirements pose new challenges on access network selection scheme, i.e., selecting the optimal network for multi-interface mobile terminal (MT) in the case that multiple networks are available. In this paper, the theory of neural network (NN) is applied in designing network selection scheme for heterogeneous networks and an NN-based access network selection algorithm is proposed, which models the network characteristics based on network and user sample data and then evaluates the performance of candidate networks based on current network and service features, the candidate network with the best service performance is then chosen as the destination network. Simulation results demonstrate that the proposed algorithm offers better QoS performance comparing to the traditional algorithm.**

***Index Terms*—heterogeneous network; neural network; back propagation; network selection; network modeling.**

I. Introduction

Next generation wireless networks (NGWN) is expected to integrate different wireless access technologies such as cellular network, wireless local area network (WLAN), worldwide interoperability for microwave access (WiMAX) and mobile ad hoc network (MANET) etc. in a seamless manner, such that the performance of wireless connectivity can be improved and user seamless mobility can be guaranteed. However, the heterogeneity and incompatibility of access network technologies, and the variety of user applications with different QoS requirements pose new challenges on network selection scheme, i.e., choosing the optimal candidate network which offers the best user QoS performance, among multiple available access networks.

As the relationship between network characteristic parameters and user QoS performance is of complex nonlinearity, the exact mathematical description is prohibited. Alternatively, neural network (NN) [1], with rapid response ability and flexible self-organizing, self-learning ability, can be applied as a promising candidate for modeling nonlinear system and solving system optimization related issues. As a matter of fact, many research works on applying NN modeling in wireless communication areas have been conducted in recent years. In [2], a learning theory based on NN modeling for objective and non-intrusive prediction of video quality over WLAN and UMTS networks is proposed. In [3], the authors probe into the handoff scheme and propose to establish geographical fingerprint based on NN modeling and the transmitted power of access point (APs) is adjusted according to the received signal strength (RSS).

Some research works apply NN modeling in heterogeneous integrated systems for resource management and access network selection. In [4], an NN based access network modeling method is proposed and an adaptive parameter adjustment algorithm based on NN model is presented. An admission control scheme based on fuzzy Q-learning algorithm is proposed in [5] for WCDMA and WLAN integrated networks supporting multimedia traffic. In [6], a fuzzy neural joint radio resource management (JRRM) algorithm is proposed, which jointly manages common radio resources of heterogeneous access networks, such that connection dropping and blocking probabilities can be reduced under the condition that user dissatisfaction probability keeps below certain threshold. In [7], a predictive RSS based vertical handoff algorithm for heterogeneous wireless networks is proposed. Back-propagation (BP) NN theory is applied for RSS prediction to reduce call dropping probability and the number of handoffs. A multi-parameter based vertical handoff decision algorithm employing neuron-fuzzy theory is proposed in [8], which achieves the efficient utilization of system resources and reduces the number of handoffs.

Although some of the previous studies consider both terminal and network characteristics in designing network selection algorithms, the parameters associated are relatively limited, and the characteristics of user application are not fully considered. In this paper, the NN modeling method for candidate access networks is presented and an access network selection algorithm is proposed which optimally selects the access network by evaluating the service characteristics of the candidate networks.

The rest of this paper is organized as follows. In Section II, an introduction of the NN based system modeling is presented. In Section III, the NN-based access network selection algorithm is discussed in detail. In Section IV, the simulation scenario for evaluating the network selection algorithm is described and the simulation results are presented, finally, conclusions are drawn in Section V.

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II. Introduction to NN-Based System Modeling

A. An Overview of NN-Based System Modeling

In this paper, BP NN model is applied to model the characteristics of candidate access networks. BP NN model is an error back-propagation multilayer feed-forward network, which is capable of learning and storing the mapping relations between input and output parameters. The steepest descent method is applied to calculate the network weights.

B. Input-output Model

The BP NN is a multi-layer feed-forward network comprised of one input layer, one or more hidden layers, and one output layer. As an example, Fig. 1 shows a BP NN structure with one hidden layer. The numbers of nodes at the input layer, hidden layer and output layer are J, K, and L, respectively. The parameters of Fig. 1 are summarized in Table I.

In Fig. 1, the input of the kth neurons at the hidden layer can be expressed as:

$$y_k = \phi_1\left(v_k\right),\ k = 1,2,...,K, \tag{1}$$

where $v_k = \sum_{j=1}^{J} x_j \cdot v_{jk}$ is the weighted sum of the input neurons, $\phi_1(\cdot)$ denotes the activation function from the input layer to the hidden layer which reflects the activate pulse strength from input layer to the hidden layer.

Similarly, the output of the lth neuron at the output layer can be expressed as:

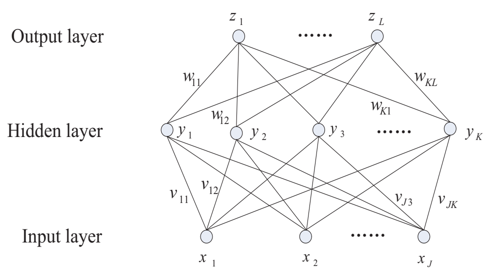

Fig. 1. BP neural network structure with single hidden layer

TABLE I. Parameters in NN Model

	Parameters
x_j	Input of the jth neuron at the input layer
v_{jk}	Weight corresponding to the jth input at the input layer and the kth input at the hidden layer
y_k	Input of the kth neuron at the hidden layer
w_{kl}	Weight corresponding to the kth input at the hidden layer and the lth input at the output layer
z_l	Actual output of the lth neuron at the output layer

$$z_l = \phi_2\left(w_l\right),\ l = 1,2,...,L, \tag{2}$$

where $w_l = \sum_{k=1}^{K} y_k \cdot w_{kl} - \theta_l$ is the weighted sum of the hidden neurons, θ_l is the threshold of the lth neurons at the output layer, $\phi_2(\cdot)$ is the activation function from the hidden layer to the output layer. The activation functions $\phi_1(\cdot)$ and $\phi_2(\cdot)$ reflect the activate pulse intensity from the lower node to the upper node.

C. Weights Determination

To model an NN-based system, the weights of the NN model, i.e., v_{jk} and w_{kl}, for j=1, 2,…, J, k=1, 2, …, K, and l=1,2,…,L, can be determined by iterative method. Given training data samples of the system, including the input parameters, the desired and the actual outputs, the weights v_{jk} and w_{kl} can be calculated through minimizing the mean square error (MSE) between the desired and the actual outputs, i.e.

$$\text{minimize } E = \frac{1}{2}\sum_{r=1}^{R} e^{(r)} = \frac{1}{2}\sum_{r=1}^{R}\sum_{l=1}^{L}\left(d_l^{(r)} - z_l^{(r)}\right)^2, \tag{3}$$

where R denotes the total number of the training patterns, $d_l^{(r)}$ and $z_l^{(r)}$, respectively, denote the lth desired and actual output parameters of the rth pattern.

From the rth to the (r+1)th iteration, the weights updating formulas can be expressed as:

$$v_{jk}^{(r+1)} = v_{jk}^{(r)} + \gamma \cdot \Delta v_{jk}^{(r)}, \tag{4}$$

$$w_{kl}^{(r+1)} = w_{kl}^{(r)} + \gamma \cdot \Delta w_{kl}^{(r)}, \tag{5}$$

where γ denotes the studying rate, $\Delta v_{jk}^{(r)}$ and $\Delta w_{kl}^{(r)}$ denote the weight variations at the rth iteration and can be calculated as follows:

$$\Delta v_{jk} = \frac{\partial e}{\partial v_{jk}} = \sum_{l=1}^{L}\left(d_l - z_l\right)\cdot \varphi'\left(w_l\right)\cdot w_{kl} \cdot \varphi'\left(y_k\right)\cdot x_j, \tag{6}$$

$$\Delta w_{kl} = \frac{\partial e}{\partial w_{kl}} = \left(d_l - z_l\right)\cdot \varphi'\left(w_l\right)\cdot y_k, \tag{7}$$

The modeling process is completed when the error E is within a predefined error range and the obtained optimal set of weights characterizes the nonlinear relationship of the input and output parameters of a given system.

III. The Proposed Access Network Algorithm

To evaluate the user QoS characteristics in both the WLAN and UMTS networks, the nonlinear relationships between user/system characteristics parameters and the user QoS parameters are modeled based on NN theory for both the UMTS and WLAN. Based on the models, the performance of the candidate access networks can be evaluated and the optimal candidate access network corresponding to the best user service performance can be selected.

A. Access Network Characteristics Modeling

To model the service characteristics of one user in an access network, the RSS and data rate R of the user and the background traffic B, which represents the traffic loads of other users, are chosen as input parameters, and the connection delay, throughput, and packet loss rate of the user, denotes as DE, T and DR are chosen as service character parameters. The definition of input parameters and service characteristics parameters of the access network are shown in Table II.

The access network modeling process based on NN theory can be summarized as follows:

Step 1: Initializing modeling error threshold ε, learning times *r*, the maximum number of learning *R*, let $r=0$. Assuming that the total number of samples is *S*, denoting sample sequence number as *s*, let $s=1$. Initializing v_{jk} and w_{kl}, and denoted as $v_{jk}^{(0)}$, $w_{kl}^{(0)}$, respectively, and initializing θ_l. The activation function $\phi_1(\cdot)$ and $\phi_2(\cdot)$ are respectively chosen as a continuous value Sigmoid function and linear function:

$$\phi_1(\cdot)=\phi_1(x)=\frac{1}{1+e^{-x}}, \tag{8}$$

$$\phi_2(\cdot)=\phi_2(x)=x, \tag{9}$$

Step 2: The input parameters B, RSS, R of the *s*th set of the sample data are respectively denoted by $x_{1,s}$, $x_{2,s}$, $x_{3,s}$, i.e., $x_{1,s}=B_s$, $x_{2,s}=RSS_s$, $x_{3,s}=R_s$. The desired output of service characteristics parameters of the *s*th set of the sample data are respectively denoted by $d_{1,s}$, $d_{2,s}$, $d_{3,s}$, i.e., $d_{1,s}=DE_{s,d}$, $d_{2,s}=T_{s,d}$, $d_{3,s}=DR_{s,d}$, go to Step 3.

Step 3: Substituting $x_{1,s}$, $x_{2,s}$, $x_{3,s}$ and $v_{jk}^{(r)}$, $w_{kl}^{(r)}$, θ_l into Eq. (1) and (2), the actual output of the *s*th set of input parameters can be obtained, denoted by $z_{1,s}=DE_s^{(r)}$, $z_{2,s}=T_s^{(r)}$, $z_{3,s}=DR_s^{(r)}$.

Step 4: Substituting the desired outputs $DE_{s,d}$, $T_{s,d}$, $DR_{s,d}$ and the actual outputs $DE_s^{(r)}, T_s^{(r)}, DR_s^{(r)}$ of the *s*th set into Eq. (6) and Eq. (7), and calculating the connection weights variation $\Delta v_{jk}^{(r,s)}$ and $\Delta w_{kl}^{(r,s)}$ during the *r*th learning process. If *s*<*S*, then *s*=*s*+1, go to Step 3, else go to Step 5.

Step 5: Calculating connection weights variation $\Delta v_{jk}^{(r,s)}$ and $\Delta w_{kl}^{(r,s)}$ of all the sample data during the *r*th learning process, denoted by:

$$\Delta v_{jk}^{(r)}=\sum_{s=1}^{S}\Delta v_{jk}^{(r,s)}, \tag{10}$$

$$\Delta w_{kl}^{(r)}=\sum_{s=1}^{S}\Delta w_{kl}^{(r,s)}, \tag{11}$$

Substituting $\Delta v_{jk}^{(r)}$ and $\Delta w_{kl}^{(r)}$ into Eq. (4) and (5), $v_{jk}^{(r+1)}$ and $w_{kl}^{(r+1)}$ can be obtained.

Step 6: Calculating MSE between the desired and actual output:

$$E=\frac{1}{2}\sum_{s=1}^{S}\sum_{l=1}^{3}\left(d_{l,s}-z_{l,s}\right)^2. \tag{12}$$

If $E<\varepsilon$, go to Step 7, elseif *r*<*R*, then let *s*=1, *r* = *r* +1, go to Step 2, else go Step 8.

Step 7: The process of access network is completed. The nonlinear relationship between the input parameters and the output service characteristics which is characterized by the connection weights v_{jk} and w_{kl} are obtained.

Step 8: Modeling algorithm fails.

TABLE II. ACCESS NETWORK INPUT PARAMETERS AND SERVICE CHARACTERISTIC PARAMETERS

Input parameters x_j	Background traffic	B
	Receiving signal strength	RSS
	Service rate	R
Actual output z_l	Delay	DE
	Throughput	T
	Packet loss rate	DR
Desired output d_l	Delay	DE_d
	Throughput	T_d
	Packet loss rate	DR_d

B. The Optimal Network Selection Scheme

Assuming the number of candidate access networks is *N*, the input user and network characteristic parameters are collected by MTs which are about to conduct access network selection. Inputting user and network characteristic parameters to the NN-based models of the access networks, the output characteristics of the candidate networks can be obtained. By evaluating the service characteristics of access networks, the optimal access network can be selected. The specific process can be described as follows:

1) Terminal and network information collection

The MTs which intend to select access network collect terminal and network information, including background traffic *B*, receiving signal strength *RSS* and data rate *R*, etc.

2) Obtaining the characteristic parameters of candidate networks.

Inputting collected user and network characteristic parameters into the NN-based models of the access networks, the output characteristics, including delay *DE*, throughput *T*, packet loss rate *DR* of the candidate networks can be obtained.

3) Optimal network selection based on service performance

For a particular user service type, one or more service sensitive parameters can be determined, and the candidate network with the best performance in terms of the service sensitive parameter(s) should be chosen as the destination access network. For instance, small delay should be guaranteed for voice services, while large throughput and small packet loss rate should be guaranteed for data services, large throughput and small delay jitter should be guaranteed for video streaming services.

For instance, as the voice service is more sensitive to delay, the i^* th access network with the lowest connection delay should be chosen as the target network among all N candidate networks, i.e.,

$$i^* = \arg\min_{i\in[1,N]} \left(DE_i \right), \tag{13}$$

Similarly, for data services, large user throughput and small packet loss rate should be guaranteed, thus both user throughput and packet loss rate are chosen as service sensitive parameters. Applying multiple attribute decision method, the optimal network i^* can be selected, i.e.,

$$i^* = \arg\max_{i\in[1,N]} \left(\gamma_1 \frac{T_i}{\max(T_i)} + \gamma_2 \left(1 - \frac{DR_i}{\max(DR_i)} \right) \right), \tag{14}$$

where γ_1 and γ_2 denote the weighting factors corresponding to the parameters T and DR, respectively.

IV. Simulation and Analysis

In order to verify the effectiveness of the proposed NN-based access network selection algorithm, a heterogeneous network model which integrates UMTS and WLAN is created based on the Network Simulator 2 (NS-2) software package [9]. The network service characteristics are simulated and the network modeling sample data can be obtained. Based on the network sample data, the NN-based access network models are established by using Matlab [10]. For a particular MT intends to perform network selection, real-time service and network parameters are determined and the output serviced performance can be obtained based on the NN-based model. Finally, the performance of the proposed algorithm is evaluated based on NS-2 and compared with the traditional network selection algorithm which is based on the network default priority.

A. Obtaining the Network Modeling Sample Data through NS-2

The simulation scenario based on NS-2 is a heterogeneous wireless network of UMTS and WLAN. Assuming UMTS covers the entire area while WLAN covers hot areas only and MTs in the system have two communication interfaces respectively connected to the Node B of UMTS and the AP of WLAN, and communicates with the correspond node (CN). The simulation network topology is as follows shown in Fig. 2.

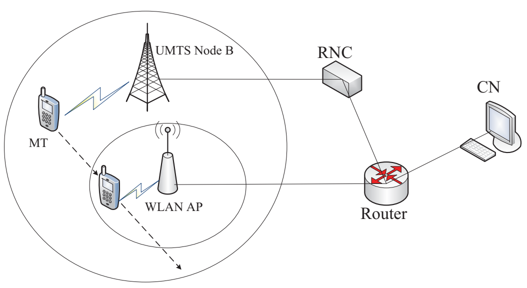

Fig. 2. The communication topology of an MT in a heterogeneous environment

In the simulation, the UMTS bandwidth is set to 384Kb/s and the WLAN bandwidth is set to 11Mb/s. Assuming that the data service between CN and MT is 0.5Mbps CBR traffic flow with packet size being 500 bytes, and the traffic of other users are modeled as Pareto distributed background traffic. The network background traffic B, user data rate R and received signal strength RSS are chosen as the input parameters of the model. Given input parameters, the service characteristics output parameters, i.e., connection delay DE_d, user throughput T_d and packet loss rate DR_d can be obtained. As an example, Table III lists 10 sets of sample data of WLAN obtained from NS-2 simulation.

TABLE III. The Sample Data in WLAN

sequence number	**Input parameters**		
	Background Traffic (Mb)	***Data Rate (Mb)***	***Receive Signal Strength (10e-9w)***
1	1	0.5	7.76759
2	1	1	6.69756
3	1	2	4.05161
4	2	0.5	2.71224
5	2	0.5	7.76759
6	2	1	20.5113
7	2	2	16.2065
8	3	0.5	1.67439
9	3	1	5.12782
10	3	2	2.10036
Sequence number	**Output parameters**		
	Throughput (kb/s)	***Delay (ms)***	***Packet loss rate (%)***
1	488.28125	51.182	0.0
2	960.9375	82.401	2.4096
3	1816.40625	74.199	12.2244
4	468.75	62.589	4.8387
5	375.0	71.665	22.5806
6	867.1875	71.238	14.8594
7	1449.21875	82.071	25.8517
8	316.40625	59.478	37.9032
9	687.5	68.315	33.7349
10	1640.625	60.377	22.8457

B. NN-based Access Network Modeling in Matlab

Given the network sample data, the NN-based network models can be established by using Matlab, and the nonlinear relationship between the network input parameters (B, R and RSS) and the output parameters of user service characteristics (DE, T and DR) can be obtained.

In the modeling, the numbers of the neurons in the input layer, hidden layer and output layer are set to 3, 10 and 3 respectively. The modeling error threshold is set to 10^{-4}. The UMTS and WLAN network models can be established according to the modeling process described in Section II and III, and the connection weights v_{jk} and w_{kl} can be obtained.

From the simulation, the connection weight matrix V between the input layer and the hidden layer of WLAN is obtained as following:

$$V = \begin{pmatrix} -15.706 & -49.332 & -8.174 & -0.752 & 99.041 & -7.748 & 58.820 & 0.529 & 48.467 & -13.030 \\ 15.931 & -74.529 & -13.727 & 4.747 & -72.376 & 8.456 & -13.083 & 5.712 & 79.930 & 0.818 \\ 19.209 & 18.709 & 4.035 & 0.269 & 62.183 & 7.050 & -32.458 & -5.928 & 49.752 & -2.030 \end{pmatrix},$$

and the connection weight matrix W between the hidden layer and the output layer of WLAN is obtained as follows:

$$W=\begin{pmatrix} -0.398 & 0.714 & -1.514 & 4.432 & -1.066 & -1.932 & 0.571 & -2.461 & -1.002 & 0.145 \\ 0.381 & -4.691 & 5.871 & -6.383 & 7.218 & 3.483 & -2.986 & 11.778 & 3.775 & 2.074 \\ 8.989 & -1.764 & 7.844 & -29.732 & 8.631 & 16.780 & -1.198 & 22.811 & 7.557 & 0.205 \end{pmatrix}^T$$

Fig. 3 shows the MSE versus the number of the iterations for modeling the WLAN network. It can be seen from the figure that when the number of the iterations is larger than 585, the MSE becomes less than the error threshold 10^{-4}, indicating the modeling process has become converged. Similarly, the NN-based model for the UMTS can be conducted and the convergence of the modeling process can be verified.

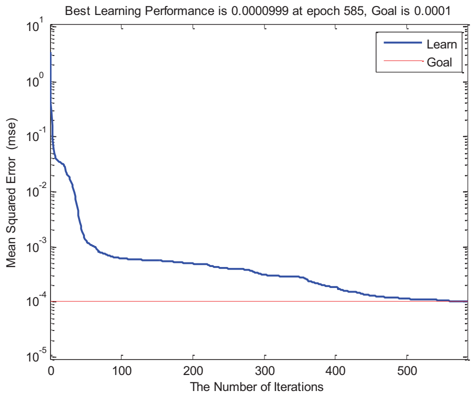

Fig. 3. The MSE versus the number of iterations

C. Simulation Results

In this subsection, the performance of the proposed algorithm (algorithm B) is evaluated based on NS-2 and compared with the traditional algorithm (algorithm A) which is based on the network default priority, i.e., the priority of WLAN is higher than that of UMTS, thus when an MT is in the overlapped area of UMTS and WLAN, it chooses to access to the WLAN, only if it is in the UMTS area while no WLAN is available, the MT chooses to access to the UMTS. In the proposed algorithm, during network selection process, the service performance of candidate access networks is predicted through NN-based modeling and the candidate network with the optimal performance of service sensitive parameters corresponding to the user service type is selected as the target network.

In the simulation scenario described in Fig. 2, one MT starts to move to the area of WLAN with the speed of 1m/s at the beginning of simulation. In the 20th seconds, the MT enters into the coverage area of WLAN and it moves out of the WLAN in the 120th seconds. The simulation is completed in the 130th seconds. Assuming that no background traffic before the 60th seconds, at the 60th seconds, the background traffic which is characterized by 2Mbps Pareto distributed traffic, increases rapidly due to a large number of other users accessing to the WLAN, then after 40 seconds, i.e., from the 100th seconds, the other users stop using the WLAN, resulting in no background traffic.

Fig. 4 and Fig. 5 plot the user throughput for using algorithm A and B, respectively. Fig. 6 and Fig. 7 plot the end to end delay for using algorithm A and B, respectively. Fig. 8 plots the packet loss rate for different network background traffic. From Fig. 4 to Fig. 7, the curve UMTS denotes that the MT selects the UMTS to communicate with the CN, the curve WLAN denotes that the MT selects WLAN to communicate with the CN.

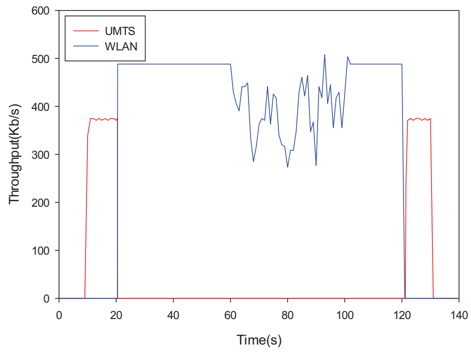

Fig. 4. The average throughput of MT by adopting the algorithm A

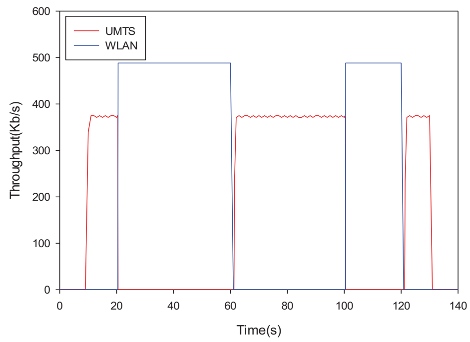

Fig. 5. The average throughput of MT by adopting the algorithm B

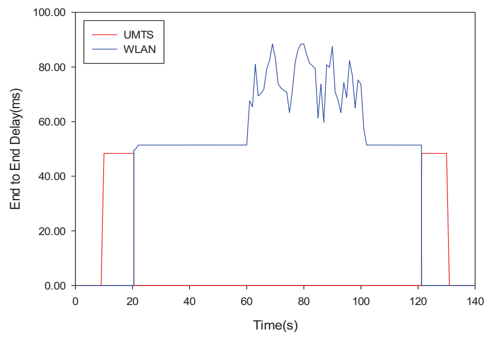

Fig. 6. The end to end delay of MT by adopting the algorithm A

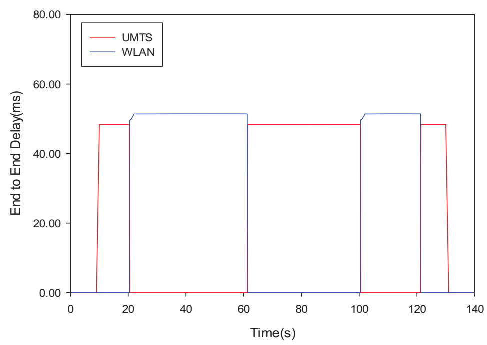

Fig. 7. The end to end delay of MT by adopting the algorithm B

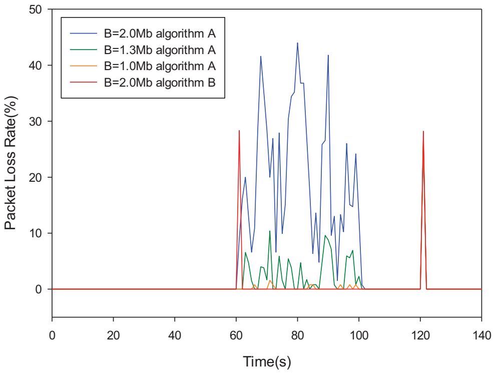

Fig. 8. The packet loss rate of MT by adopting the algorithm A and B

It can be seen from Fig. 4 to Fig. 8 that, in the first 20 seconds, as the MT is only in the coverage area of UMTS, it chooses to access to UMTS. From the 20th second to the 60th second, the MT moves into the coverage area of WLAN. According to the algorithm A, the MT selects the WLAN to access due to the higher priority of WLAN. While according to the proposed algorithm B, based on the NN models, the output service characteristics corresponding to accessing to both UMTS and WLAN can be obtained. As the average throughput offered by WLAN is larger than that from UMTS and the packet loss rate in the UMTS and the WLAN are small during the time period. Hence, the WLAN is chosen to be the destination access network according. From the 60th second to the 100th second, as the background traffic increases in WLAN, resulting in the decrease of the average throughput and the increase of the end to end delay and packet loss rate in WLAN. According to the algorithm A, the MT selects the WLAN despite of the increase of background traffic in WLAN, while from the proposed algorithm B, the MT may choose to select the UMTS for the better performance UMTS offering. From the 100th second, as the other users complete the communication in WLAN, the performance of WLAN becomes better than that of UMTS, thus from both algorithms, the MT chooses to access to WLAN. When the MT moves out of the coverage area of WLAN, it accesses to UMTS again. From the entire simulation process, it can be seen that by adopting the proposed NN-based algorithm, the total throughput of the MT increases and the end to end delay and the total packet loss rate decrease compared to the traditional algorithm A.

V. CONCLUSION

In this paper, we address the problem of network selection in heterogeneous wireless networks and an NN-based access network selection algorithm is proposed. The access network models are established based on NN theory. The user and network characteristics input parameters are collected and the output characteristics of the candidate networks are obtained by MT based on the NN model. By evaluating the service characteristics of the candidate access networks, the optimal access network selection can be achieved. The simulation results show that the proposed algorithm offers better QoS performance than the traditional algorithm.

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