A User-preference-aware Terminal-controlled Access Network Selection Scheme in Heterogeneous Wireless Networks

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***Abstract*—The coexistence and integration of multiple radio access technologies (RATs) deployed by different network operators are fundamental for next-generation mobile communication systems. In heterogeneous wireless environments, the access network selection, which is to select the most suitable network(s) for a terminal equipped with multiple radio interfaces according to various selection strategies, is a very important issue resulting in the performance maximization. In this paper, we propose a terminal-controlled access network selection scheme with parallel transmission capability for heterogeneous wireless networks, in which the suitable network(s) is(are) selected to access according to the total utility of different access networks. And the utility of each RAT is calculated based on the user preference and multiple access network criteria. Furthermore, the terminal-controlled access network selection with parallel transmission is formulated as a multi-constraint Knapsack problem which is solved with the exhaustive method to an optimum combination of RATs. Our proposed scheme is user-preference-aware, cost-aware, power-aware, and QoS-oriented. Simulation results show that our proposed access network selection scheme with parallel transmission can greatly improve the achieved data transmission rate with only a little increment in the cost and power consumption.**

Keywords—Heterogeneous wireless networks; Access network selection; Utility; Parallel transmission

I. INTRODUCTION

The fourth generation of mobile communication system is expected to meet the continuously increasing requirements of users. To satisfy these requirements, it is necessary to integrate heterogeneous radio access networks, such as Universal Mobile Telecommunications Systems (UMTS), Long Term Evolution (LTE), Wireless Metropolitan Access Networks (WMANs), Wireless Local Access Networks (WLANs), and so on.

In heterogeneous network environments, to ensure users always best connected anywhere and anytime to different access networks, multi-mode mobile terminals (MMTs) equipped with multiple radio network interface cards (NICs) should be able to perform sense, make selection and handle handover among the existed RATs surround them. Therefore, the access network selection issue should be investigated to select the best available RAT(s) that satisfies (satisfy) the users' quality of service (QoS) requirements.

Existing access network selection schemes in heterogeneous wireless networks can be classified into three categories, network-controlled, terminal-controlled and hybrid. In network-controlled schemes, network operators keep tight control over users to make the most profitable use of networks, where terminal users can only influence their preferences in a limited way. In terminal-controlled schemes [1-3], users have greater control of their terminal behavior and can select the most satisfying network(s) to connect since their MMTs can store user preferences, and are in an efficient position to collect information about their own capabilities and surrounding RATs. It is suitable that the MMT makes the selection on its own. In hybrid schemes, access network selection decisions are made based on the information provided by both the network and the terminal. However, more constraints are considered and the hybrid system seems more complicated.

In [4] and [5], a comparative survey of the access network selection issue is presented, and a variety of algorithms have been proposed, such as fuzzy logic, multiple-attribute decision making, data prediction algorithm, game theory, utility function, context-aware concept, etc. Most of these existing algorithms only consider the situation that the MMT selects the most one suitable network to access. If the radio interfaces of an MMT can work simultaneously, the MMT is able to select more than one network to access, and data packets are transmitted through these connected wireless links in parallel. With this mechanism, the transmission performance of the MMT can be effectively enhanced. However, there are only a few works considering the parallel transmission in heterogeneous wireless networks [3, 6-7]. The joint resource allocation problem with parallel transmission is investigated in [6], and a vertical handoff decision algorithm with parallel transmission capability is presented in [7]. Both of them are not focused on the terminal-controlled but network-controlled access network selection problem. In [3], a network access selection scheme, which only considers two criteria, power and throughput, is proposed, and two criteria are apparently not quite enough for the MMT to choose the most satisfying network(s). Hence, it is necessary to improve the existing methods. We focus on the terminal-controlled scheme with parallel transmission and consider more criteria in this work.

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In this paper, we propose a terminal-controlled access network selection scheme with parallel transmission in heterogeneous wireless networks. In our scheme, the access networks are selected in order that the total utility of the MMT is maximized, where the utility of each RAT is calculated according to five network criteria and the user preference. With some constraint conditions, the terminal-controlled access network selection with parallel transmission in heterogeneous wireless networks is formulated as a multi-constraint Knapsack problem. Then, the formulated problem is resolved using the exhaustive method, and a set of access networks resulting in the total utility maximization is the most suitable selection for the terminal user.

II. System Model

A system model, where J access networks, {RAT 1, RAT 2, …, RAT J}, are available for each terminal, is considered, as shown in Fig. 1. Each MMT equipped with N ($J>N$) NICs can access multiple RATs through parallel transmission. There are two modules in the MMT to implement the access network selection, the NIC management module and the access network selection management module. In the NIC management module, the information about the terminal and its surrounding RATs is collected periodically and delivered to the access network selection management module. The access network selection management module performs the access network selection decision.

From the perspective of users, there are many parameters and information can be collected and used for access network selection, such as the residual bandwidth, cost, interface power, the quality of wireless link, the access network load, and so on.

Residual bandwidth (r): The residual bandwidth of an access network is related to the maximum achievable data rate and the network conditions. It is an important criterion to measure the network's capability.

Cost (c): The cost of using a particular access network is a major criterion and potentially a decisive factor in the terminal-controlled access network selection. In a given time, it depends on the data rate through the connected wireless link(s).

Interface power (p): The interface power is the power consumed by an active NIC. As the battery of MMTs is limited, users care much about the energy efficiency, especially when the NICs work simultaneously.

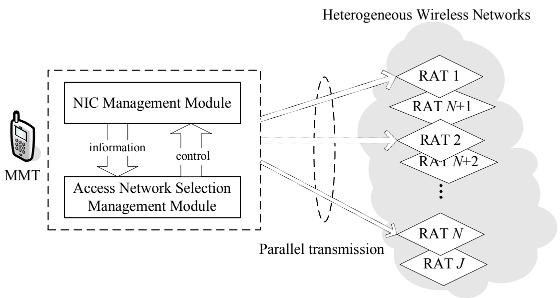


Fig. 1. The heterogeneous wireless network framework for the terminal-controlled access network selection

Link quality (S): The quality of the wireless link in terms of signal to noise ratio (SNR) or signal to interference noise ratio can properly reflect the transmission quality of the wireless channel. To avoid the high outage or error probability during transmission, the access networks with good link quality are preferred by users.

Access network load (l): The access network load indicates the degree of the access network occupied by other users, varying from 0 (unloaded) to 1 (heavily loaded). It should be informed to users by the access networks. The access network load is also a major criterion for access network selection.

In order to satisfy the users' requirements better, the MMT integrates an access network selection graphical user interface (GUI) to help users configure their preferences for the mentioned criteria. For example, some users may prefer the RATs with high data rate, while some may prefer the RATs with low cost or power consumption.

Based on the user preference and the criteria of RATs, the access network selection management module decides the suitable RAT(s) to access, and the control message is fed back to the NIC management module to connect the corresponding interfaces. Therefore, the access network selection policy is the most important issue and we should resolve the problem based on the user preference and the criteria of RATs for heterogeneous network environments.

III. Proposed Access Network Selection Scheme

As illustrated in Fig. 1, the MMT equipped with N NICs accesses network(s) from J RATs. The network selection criteria of each RAT, namely the residual bandwidth (r), cost (c), interface power (p), link quality (S) and access network load (l), are considered. For each criterion m, a normalized value α_m ($0 \le \alpha_m \le 1$) is used to present the preference weight which can be evaluated through different levels of priority: high, medium, low and without consideration. Each level is associated with a discrete value, w_m, varying from 3 (high) to 0 (without consideration), and w_m is set by the user through the GUI of the MMT. Therefore, α_m can be calculated as

$$\alpha_m = w_m \Big/ \sum_{i=1}^{M} w_i \tag{1}$$

where M is the total number of considered criteria, and $\sum_{i=1}^{M} \alpha_m = 1$.

Based on the considered criteria and the corresponding user preference weights, the MMT calculates the utility, U_i, of each RAT i to make the access network selection. In this paper, the utility model proposed in [5] is used, that is,

$$U_i = \prod_{m=1}^{M} [u_m(x)]^{\alpha_m} \tag{2}$$

where $u_m(x)$ is the elementary utility function of criterion m, and α^m is the user preference weight of criterion m.

For an upward criterion m whose elementary utility is an increasing function, such as the residual bandwidth and link quality, and x is bounded by $x_\alpha \le x \le x_\beta$ due to technological constraints and the user's requirements, $u_m(x)$ is

$$u_m(x)=\begin{cases}0, & x<x_\alpha\\ \dfrac{\left(\dfrac{x-x_\alpha}{x_o-x_\alpha}\right)^\zeta}{1+\left(\dfrac{x-x_\alpha}{x_o-x_\alpha}\right)^\zeta}, & x_\alpha\le x\le x_o\\ 1-\dfrac{\left(\dfrac{x_\beta-x}{x_\beta-x_o}\right)^\gamma}{1+\left(\dfrac{x_\beta-x}{x_\beta-x_o}\right)^\gamma}, & x_o<x\le x_\beta\\ 1, & x>x_\beta\end{cases} \tag{3}$$

where

$$\gamma=\frac{\zeta(x_\beta-x_o)}{x_o-x_\alpha} \tag{4}$$

$$\zeta\ge\max\left\{\frac{2(x_o-x_\alpha)}{x_\beta-x_o},2\right\} \tag{5}$$

x_o is the value of parameter x at the middle point of the elementary utility function, that is, $u^m(x)$=0.5, ζ and γ are the tuned steepness parameters.

For a downward criterion m whose elementary utility is a decreasing function, such as the cost, interface power and access network load, the function form is $1-u^m(x)$, where $u^m(x)$ follows (3).

When the MMT can select multiple networks to access for parallel transmission to satisfy the user's requirements, not only the upper bound for the total cost per unit time and the total power of all the active radio interfaces, but also the lower bound for the total data rate need to be set. The combination of RATs, which maximizes the total utility and meets the constraints, should be the most appropriate access networks to be selected by the MMT. Therefore, the terminal-controlled access network selection issue with parallel transmission can be described as a multi-constraint Knapsack problem,

$$\max_{\mathbf{M}}\left\{\mathbf{U}^{\mathrm{T}}\mathbf{M}\right\} \tag{6}$$

$$\text{s.t. (C1) } \sum\nolimits_{i=1}^{J} c_i r_i\cdot\lambda_i\le C \tag{6-1}$$

$$\text{(C2) } \sum\nolimits_{i=1}^{J} p_i\cdot\lambda_i\le P \tag{6-2}$$

$$\text{(C3) } \sum\nolimits_{i=1}^{J} r_i\cdot\lambda_i\ge R \tag{6-3}$$

where $\mathbf{U}=[U_1\ U_2\ ...\ U_J]$ is the utility vector of the RATs, $\mathbf{M}=[\lambda_1\ \lambda_2\ ...\ \lambda_J]$ is the selection factor vector of the RATs, and $\lambda_i\in\{0,1\}$. If RAT i is selected to access by an MMT, λ_i=1; otherwise, λ_i=0. Since $J>N$, there are at most N elements in $\mathbf{M}$ are 1. J is the number of available RATs around an MMT, U_i is the utility of RAT i, c_i is the cost per unit data of RAT i, c_ir_i is the cost per unit time, C is the upper constraint of the total cost per unit time, p_i is the interface power of RAT i and P is the upper constraint of the total power of all the active radio interfaces, r_i is the residual bandwidth of RAT i and R is the minimal requirement of the total data rate.

The optimum selected combination of RATs can be obtained by solving the multi-constraint Knapsack problem formulated in (6). For example, if the solution is $\lambda_1=\lambda_3=\lambda_4=1$, λ_i=0 for other RATs, {RAT 1, RAT 3 and RAT 4} is the most appropriate combination of networks to access. Obviously, there are at most $C_J^N\cdot 2^N$ combinations of RATs to be considered. Since N and J are small in actual situation, we use the exhaustive method (EXM) to solve the formulated Knapsack problem in (6). The detail of the algorithm is summarized as follows.

The Access Network Selection Algorithm

1. Compute U_i of each RAT i, $1\le i\le J$.
2. For each RAT $i(1\le i\le J)$, set λ_i=0 or 1, and the number of λ_i=1 is no more than N, get $C_J^N\cdot 2^N$ combinations of RATs.
3. For each combination of RATs, compute $\sum\nolimits_{i=1}^{J} c_i r_i\cdot\lambda_i$, $\sum\nolimits_{i=1}^{J} p_i\cdot\lambda_i$ and $\sum\nolimits_{i=1}^{J} r_i\cdot\lambda_i$.
4. Eliminate the combinations which fail to satisfy the conditions (6-1), (6-2) or (6-3).
5. Within the remaining combinations of RATs which satisfy the conditions (6-1), (6-2) and (6-3), search the combination of RATs with the maximal $\mathbf{U}^{\mathrm{T}}\mathbf{M}$.
6. If none of the combinations satisfy the conditions (6-1), (6-2) and (6-3), search and select the combination of RATs resulting in the maximal $\mathbf{U}^{\mathrm{T}}\mathbf{M}$.

Based on the proposed access network selection algorithm, the MMT can select the optimum combination of access networks for parallel transmission, as well as the user preference is taken into consideration well.

IV. Performance Evaluation And Disscussion

We consider the simulation in which the user holds an MMT equipped with 4 NICs, and 6 RATs around it. In the real situation, since the values of the network criteria of each RAT may vary due to the user's mobility and the change of the network condition, we assume that the values are randomly generated from a given range periodically. The corresponding parameters are set based on [5] and shown in Table I.

TABLE I. SIMULATION PARAMETERS

	RAT i ($1 \le i \le 6$)	x_α	x_β	x_o	ζ
r (Kbps)	100~2000	100	3000	600	3
c (units/MB)	0~50	0	70	35	2
p (W)	1~5	0	6	3	2
S (dB)	0~12	0	12	4	3
l	0~1	0	1	0.5	2

According to [8] and [9], the achievable throughput connecting to RAT i can be modeled as $r_i(1\text{-}l_i)(1\text{-}p_b)$, where p_b is the bit error rate, r_i is the residual bandwidth and l_i is the access network load of RAT i. Suppose the QPSK modulation and the coherent demodulation are used, p_b is approximately

$$p_b \approx \frac{1}{2\sqrt{\pi S}} e^{-S} \tag{10}$$

In simulations, we substitute the achievable throughput for r_i in (7)~(9), and set C=60 units/MB, P=6W, R=1000 Kbps.

We assume that a video streaming runs on the MMT and the duration is 1500s. The buffer size at time t, $b[t]$, is formulated as

$$\begin{aligned} & b[0] = 10R_{\text{play}} \\ & b[t] = \max\left\{0, \min(10R_{\text{play}}, b[t-1] + rate[t] - R_{\text{play}})\right\}, \end{aligned} \tag{11}$$

where $rate[t]$ is the receiving data rate of the buffer, R_{play} is the playback rate of the application, and $10R_{\text{play}}$ is the beginning and maximal data size of the buffer. It is assumed that the network conditions change every 10s, and the MMT selects a combination of RATs for transmission. If $rate[t]<R_{\text{play}}$ at time t, $b[t]$ decreases. When $b[t]$=0, which indicates the buffer is empty, the streaming application is interrupted.

A. The Performance with Different User Preferences

We consider two user preferences, w_1=[3, 3, 2, 1, 1] and w_2=[1, 1, 3, 3, 2], indicating the different priority levels of the criteria [c, p, r, l, S], respectively. w_1 cares a high priority for low cost and power consumption, while w_2 cares more about the QoS-related criteria.

Fig. 2 shows the percent of interruption time length during the streaming session with different user preferences and playback rates. From Fig. 2, we observe that the percent of interruption time with w_1 is higher than that with w_2, which means that the average data rate of w_1 is lower than that of w_2. Moreover, as the playback rate increases, the interruption duration ratio increases.

Fig. 3 shows the total cost and power consumption with different two preferences as time accumulates. From Fig. 3, we observe that the total cost and power consumption of w_1 are less than those of w_2. Hence, it is a tradeoff among the performances of different criteria with different user

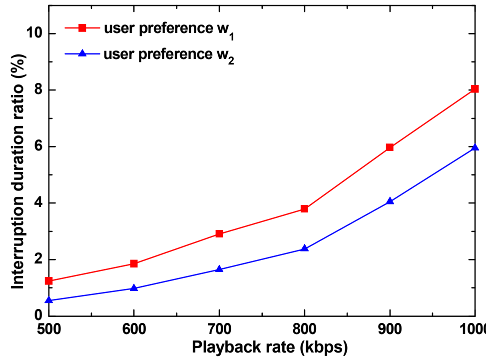
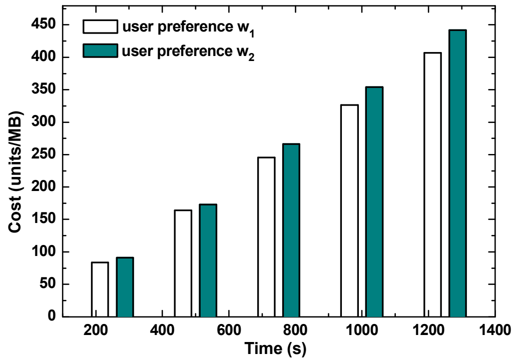
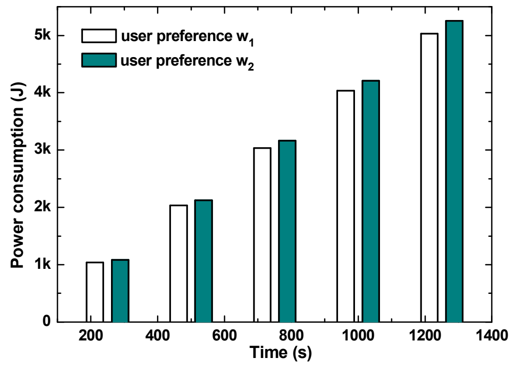


Fig. 2. The rate of different user preferences



(a) The total cost



(b) The power consumption

Fig. 3. The total cost and power consumption of different user preferences

preferences. If the user expects to achieve high date rate, the QoS-related criteria should be configured at high preference levels, while the performances of other criteria, such as the cost and the power consumption, may degrade a little. Therefore, it is very important to appropriately configure the user preference and the thresholds for different criteria in the proposed access network selection scheme.

B. The Performance Comparison Between Parallel and Single Transmissions

In the access network selection schemes with single transmission, the MMT selects the network with the highest utility, while a combination of RATs can be selected due to the parallel transmission with some constraint conditions in our proposed scheme.

Fig. 4 shows the percent of interruption time length of the two schemes with different playback rates, and Fig. 5 shows the total cost and power consumption of the two schemes as time accumulates, where w=[2, 3, 2, 3, 1]. From Fig. 4 and Fig. 5, it is obvious that the average data rate of the access network selection scheme with parallel transmission is much higher than that of the access network selection scheme with single transmission, while the total cost and power consumption of the access network selection scheme with parallel transmission are greater than those of the access network selection scheme with single transmission. Moreover, the difference between the percentages of the interruption duration of the two schemes grows exponentially when the playback rate increases, while the differences between the total cost and power consumption of the two schemes almost increase linearly as time accumulates.

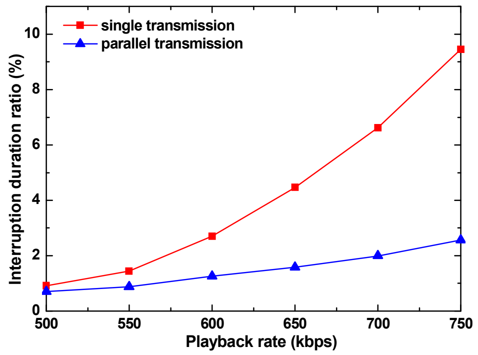
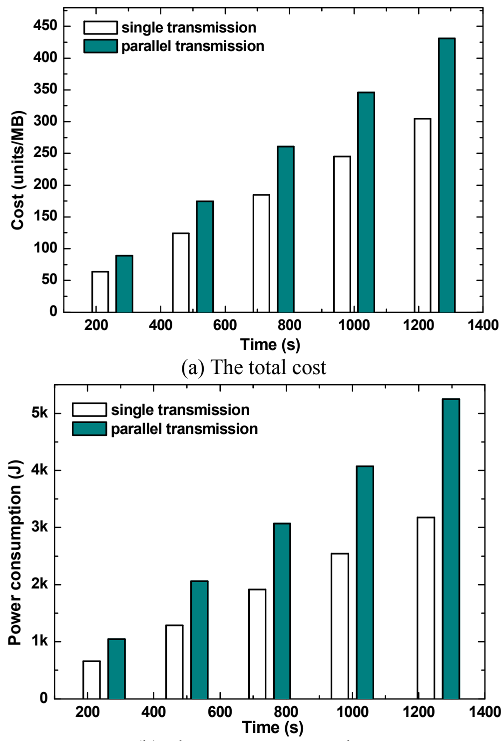


Fig. 4. The data rate of the schemes with single and parallel transmissions



(a) The total cost

(b) The power consumption

Fig. 5. The total cost and power consumption of the two schemes with single and parallel transmissions

Therefore, compared with the scheme with single transmission, the parallel transmission mechanism can greatly improve the data rate with only a little increment of the cost and power consumption.

V. Conclusions

Due to the heterogeneity of various access networks, the access network selection problem has been a hot research topic in the next generation wireless communication system. Hence, we propose a terminal-controlled access network selection scheme in heterogeneous wireless networks, in which the user preference, multiple network criteria of each RAT and the parallel transmission capability of the MMT are taken into consideration. In our work, the access network selection problem to maximize the total utility is formulated as a multi-constraint Knapsack problem, the exhaustive method is used to resolve the formulated problem, and an optimum combination of RATs is selected. Simulation results show that the user preference and the constraints for different criteria should be set appropriately in order to satisfy the users' requirements. Moreover, since the data rate increases greatly in a little price of the total cost and power consumption, the parallel transmission capability is useful.

This work is a step towards developing the MMTs with enhanced capabilities to satisfy users' QoS requirements well. We will investigate how to configure the user preference more intelligently.

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