Network Selection based on Required Bandwidth Ratio in Heterogeneous Wireless Environments

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Abstract—**The optimal network selection problem is one of the key issues in heterogeneous wireless environments. This paper proposes a network selection scheme based on the required bandwidth ratio, which estimates the bandwidth required to satisfy the quality of service (QoS) requirements of the target service. Required bandwidth ratio can be estimated from the required bandwidth and the available bandwidth of each access path. Therefore, the QoS requirements and the network load can be reflected in network selection by employing the required bandwidth ratio as one of the criteria. The network selection criteria also include access cost and power consumption rate. User preference is used to calculate the weighting factor of each criterion. The proposed scheme can also support multiple network selection by considering diversity gain and multiplexing gain. Simulation results show that the proposed scheme can achieve higher QoS in the heterogeneous wireless environments with a few heavy-loaded access networks.**

I. INTRODUCTION

In heterogeneous wireless environments, the system performance and the quality of service are much affected by the access network because each network has different advantages and disadvantages in terms of data rate, bandwidth, power consumption, cost, and so on. Therefore, selection of the most suitable access network has become an important topic.

A number of network selection schemes have been proposed recently. A decision process for a network assisted network selection mechanism that combines non-compensatory and compensatory multiple attribute decision making (MADM) algorithms has been proposed in [1]. And a cost function based network selection strategy has been presented in [2]. And an interface selection scheme based on the bandwidth estimation has been proposed in [3]. And [4] introduced a measurement-based network selection technique. A user-centric access network selection and interface management algorithm was also proposed in [5].

However, all the mentioned works above did not consider the case that a mobile terminal connects to two or more networks simultaneously. In that case, the mobile terminal must determine whether it will connect to a single access network or multiple access networks. If it is determined that the mobile terminal will connect to the multiple access networks, the mobile terminal has to determine whether it will achieve a diversity gain or a multiplexing gain. These aspects were not taken into account in the existing network selection schemes. Moreover, the QoS requirements of the target application services and the effects of received signal strength were not considered in the existing works. Therefore, in this paper, we propose a QoS-aware multi-network selection scheme for multi-homed mobile terminals in the heterogeneous wireless environments.

II. PROPOSED NETWORK SELECTION SCHEME

This paper proposes a required bandwidth ratio-based network selection scheme, which estimates the bandwidth required to satisfy the QoS requirements of the target applications. The required bandwidth can be estimated from the received signal strength of each access path and the QoS requirements such as delay, packet loss, burst size, etc. And the required bandwidth ratio can be estimated from the required bandwidth and the available bandwidth of each access network. Therefore, the QoS requirements and the signal strength can be reflected in network selection by employing the required bandwidth ratio as one of the selection criteria. The network selection criteria also include the access cost and the power consumption rate. And the user preference is used to calculate the weighting factor of each criterion. The detailed descriptions will be given in the following sections.

A. Network Selection Criteria

1) Cost: The cost of using a particular access network is an important factor in a user-centric approach. Generally, there are two kinds of cost model: cost based on the duration for voice calls and cost based on the volume of downloaded and uploaded data for data services.

2) Power Consumption: Battery lifetime is a critical factor in mobile devices. Since the majority of power consumption is related to the radio interfaces, selecting an access network which consumes less power than other networks is one of the key goal of this work.

3) Required Bandwidth Ratio: Each access network has distinctive characteristics such as data rate, modulation and coding scheme, spectral efficiency, bandwidth, and so on. And each service has its own QoS requirements such as delay, jitter, packet loss, etc. Thus, we will introduce a quantitative factor, required bandwidth, which is calculated from the characteristics of access networks and the QoS requirements of the application services. In addition, available bandwidth is also taken into account because an access network with heavy load may not guarantee QoS although its signal strength is strong enough. Required bandwidth ratio can be obtained by dividing the required bandwidth by the available bandwidth. The Available bandwidth can be extracted from the system information which is periodically broadcasted by access points in most wireless networks.

4) User Preference: Some users may prefer the cheaper access network with a moderate QoS level rather than the access network which guarantees high QoS level with high cost. On the other hand, some users may prefer the access network with a high QoS level regardless of the access cost. Therefore, in this work, weighting factors are determined according to the user preferences.

B. Effective Data Rate

We define effective data rate as the data rate required to satisfy the QoS requirements of target service. Different application services correspond to different QoS requirements, such as delay bound, data rate, packet loss ratio bound, etc. Effective data rate is dependent on not only data rate, but also delay bound, packet loss ratio. For instance, shorter delay bound requires higher data rate, and the lower packet loss ratio bound requires higher data rate because the number of required retransmission is increasing. Effective data rate of the path i can be obtained as

$$ER_i = g \times s_i \times (1 - L), \tag{1}$$

where g is the required data rate considering delay bound, peak data rate, mean data rate, and burst size. And s_i is the number of transmission required to transmit a packet successfully, and L is the packet loss ratio bound. Because the CBR voice applications always transmit packets at the peak rate, g of the CBR voice applications can be expressed as

$$g = R_{peak}, \tag{2}$$

where R_{peak} is the peak data rate which is one of the QoS requirements.

Since the VBR voice applications transmit packets only during talk-spurt duration, g of the VBR voice applications can be calculated as

$$g = \frac{\lambda \times R_{peak}}{\lambda + \alpha}, \tag{3}$$

where λ is the talk-spurt duration and α is the silence duration.

Since the video streaming applications can be modeled as a dual bucket model [6], [7], g of the video streaming applications can be obtained as

$$g = \frac{R_{peak}}{1 + D \times B^{-1} \times (R_{peak} - R_{mean})}, \tag{4}$$

where D is the delay bound, R_{mean} is the mean data rate, and B is the bucket size which can be calculated as

$$B = \frac{\sigma \times (1 - R_{mean})}{R_{peak}}, \tag{5}$$

where σ is the maximum burst size.

Since the other best effort applications usually requires mean data rate, g of the other best effort applications can be obtained as

$$g = R_{mean}. \tag{6}$$

And s_i is obtained as

$$s_i = \frac{1 - p_i^{l+1}}{1 - p_i}, \tag{7}$$

where p_i is the probability of packet loss determined by signal strength of the path i, and l is the maximum number of retransmissions.

C. Spectral Efficiency

Since each path has different SNR, appropriate MCS level is different and result in different spectral efficiency. High SNR enables the mobile terminal to use high MCS level, which requires small resources. So it is more efficient to select an access network whose spectral efficiency is higher than others. Spectral efficiency can be calculated from the MCS level which is predefined by each access network.

D. Required Bandwidth Ratio

Required bandwidth is simply calculated by dividing the effective data rate by the spectral efficiency. And the required bandwidth ratio can be obtained by dividing the required bandwidth by the available bandwidth. When the mobile terminal connects to multiple networks simultaneously to achieve diversity gain, mobile terminal will receive the same packet streams from the multiple different paths. Thus the probability of packet loss is reduced as

$$p = \prod_{i=1}^{N} p_i. \tag{8}$$

where N is the number of paths connected.

When the purpose is multiplexing gain, the mobile terminal will connect to multiple path, and each path will carry its own packet streams distinctively. Therefore, the total data rate (R_{total}) at the mobile terminal is as follows

$$R_{total} = \sum_{i=1}^{N} R_i, \tag{9}$$

where R_i is the data rate of the path i. And the packet loss probability is calculated as

$$p = \sum_{i=1}^{N} \left(p_i \times \frac{R_i}{R_{total}} \right). \tag{10}$$

E. Normalization

The values for each of the attributes are normalized because each attribute has different magnitude. Normalized values can be calculated as follows.

$$v_{normalized} = \frac{v_{ij}}{\sqrt{\sum_{i=1}^{N} v_{ij}^2}}, \tag{11}$$

where v_{ij} is the value of jth attribute on the path i.

F. Weighting

Weighting factors are determined according to the user preferences, and can be expressed as

$$A_{cost} + A_{power} + A_{RBR} = 1, \tag{12}$$

where A_{cost}, A_{power}, and A_{RBR} are the user preferences of cost, power consumption, and required bandwidth ratio, respectively.

G. TOPSIS Ranking

Euclidean distances from the weighted values of each path to the best and worst values are calculated. Finally, the path which is closest to the best value and farthest from the worst value will be selected using technique for order preference by similarity to ideal solution (TOPSIS) [8].

III. PERFORMANCE ANALYSIS

This section presents the simulation results to highlight the benefits of the proposed access network selection scheme. OPNET Modeler was used to simulate typical network selection schemes based on the signal strength, and the proposed network selection scheme.

A. Simulation Scenarios

1) Scenario 1: An access network which has the greatest SNR is selected.

2) Scenario 2: If the highest SNR is reduced below the threshold value, the access network which has the second highest SNR is selected as a secondary path to achieve a diversity gain.

3) Scenario 3, 4, 5: These scenarios use proposed network selection scheme to accomplish a diversity gain. The *Scenario 3* prefers low cost to low power consumption and high QoS, and the *Scenario 4* prefers low power, and the *Scenario 5* prefers high QoS.

4) Scenario 6: If the highest SNR is reduced below the threshold value, the access network which has the second highest SNR is selected as a secondary path to achieve a multiplexing gain.

5) Scenario 7: Proposed network selection scheme is used in this scenario. The purpose of this scenario is to obtain a multiplexing gain.

B. Simulation Settings

Fig. 1 represents the network model used in our simulation. There are 2 LTE eNodeBs, 2 LTE Home eNodeBs, and 2 WLAN APs. Since the WLAN APs are heavy loaded, 90 percents of the packets are dropped in WLAN. And the mobile terminal moves with a speed of 3km/h. The mobile terminal uses FTP download service during 30 minutes. Wireless channel models and simulation parameters are summarized in Table. I [9], [10], [11]. The cost of LTE eNB is set to 1$ per 10 MBytes, and the cost of LTE HeNB and WLAN is set to 0.1$ per 10 MBytes.

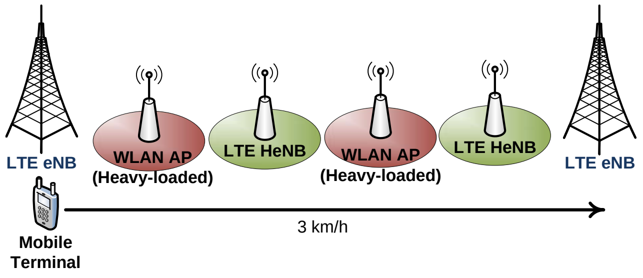

Fig. 1. Network Model

TABLE I
SIMULATION PARAMETERS

LTE eNB	
Propagation loss	$PL = 161.04 - 7.1 \log_{10}(W) + 7.5 \log_{10}(h) - (24.37 - 3.7(h/h_{BS})^2) \log_{10}(h_{BS}) + (43.42 - 3.1 \log_{10}(h_{BS})) (\log_{10}(d)-3) + 20 \log_{10}(f_c) - (3.2 (\log_{10}(11.75 h_{UT}))^2 - 4.97)$
Shadowing	6 dB
Tx power	46 dBm
LTE HeNB	
Propagation loss	$L=127+30\log_{10}R$
Shadowing	10 dB
Tx power	20 dBm
WLAN AP	
Propagation loss	$L=20\log_{10}(4\pi fd/C) + 35\log_{10}(d/d_{BP})$, $d <= d_{BP}$ $L=20\log_{10}(4\pi fd/C) + 35\log_{10}(d/d_{BP})$, $d > d_{BP}$
Shadowing	4 dB
Tx power	20 dBm
Common	
Rayleigh fading	3 dB
Noise figure	eNB : 5 dB, UE : 7 dB
Hardware loss	2 dB
Thermal noise	-174dBm/Hz

C. Performance Metrics

1) Cost: Sum of the costs of selected access networks for whole simulation time.

2) Power Consumption: Sum of the power consumed by selected access networks for whole simulation time.

3) Throughput: Sum of the size of received packets which are successfully downloaded for every second.

D. Simulation Results

Fig. 2 shows the cost of diversity mode in each scenario. The cost of *Scenario 3* is much lower than other scenarios as intended. The other scenarios do not show clear differences. Since most scenarios select the LTE eNB network at the beginning of the simulation, the cost increases linearly until the other access network is selected.

The power consumption of diversity mode in each scenario is represented in Fig. 3. The *Scenario 1* shows the least power consumption. However, the difference is not much because power consumption rates of considered access networks are

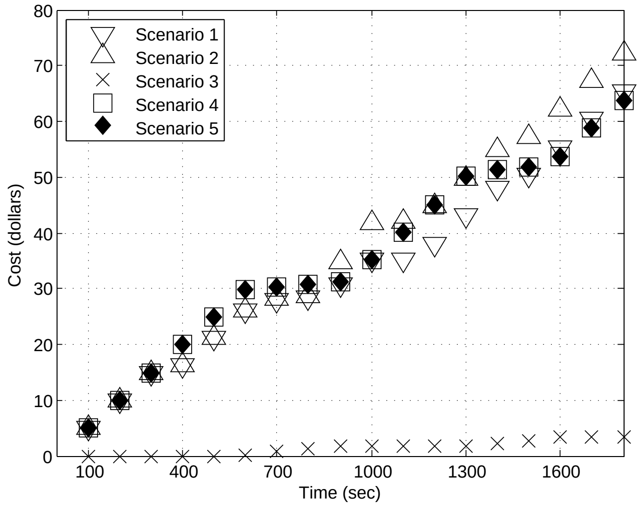

Fig. 2. Cost of Diversity Mode

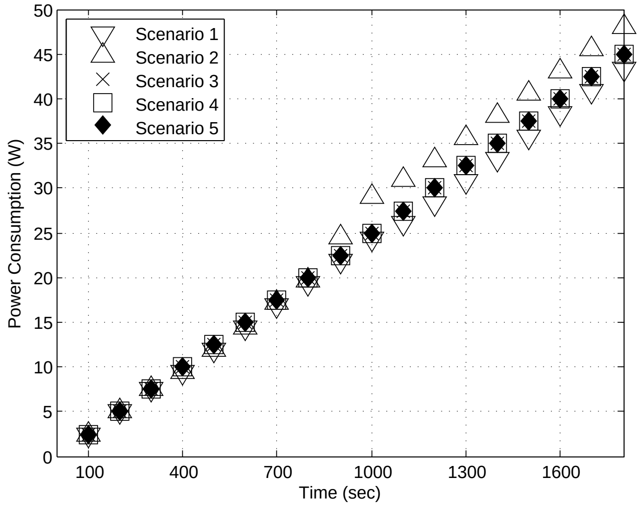

Fig. 3. Power Consumption of Diversity Mode

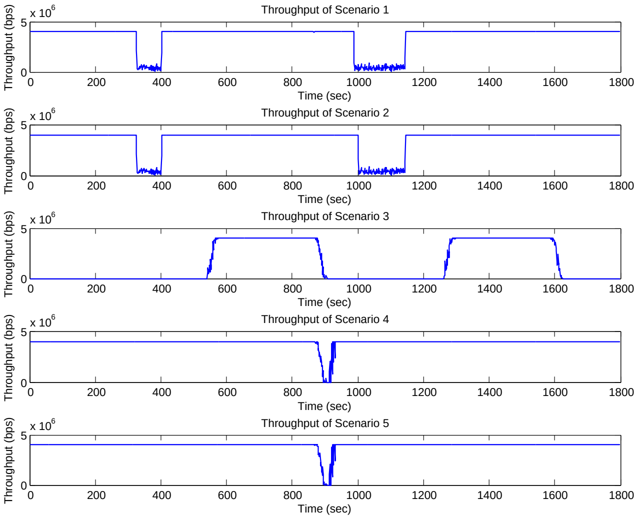

Fig. 4. Throughput of Diversity Mode

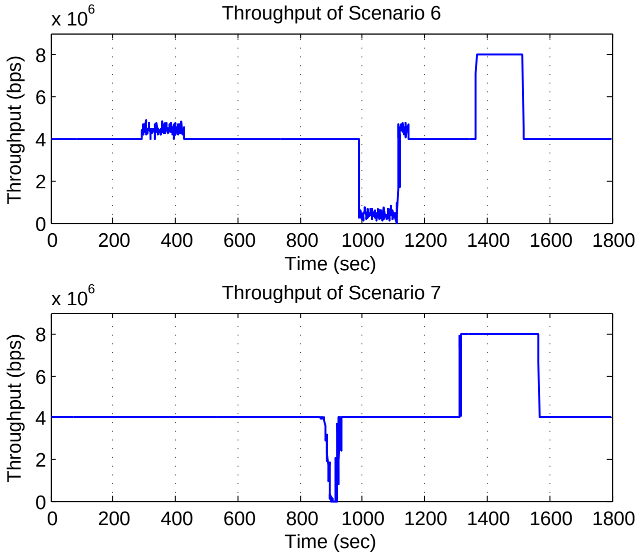

Fig. 5. Throughput of Multiplexing Mode

similar. The power consumption of *Scenario 2* is the greatest since it selects multi-connection whenever the SNR is below the predefined threshold value, regardless of the QoS requirements, the condition of other networks, and the user preferences. In *Scenario 3, 4, 5*, WLAN networks are not selected due to the low available bandwidth and the high required bandwidth ratio. Since the LTE eNB and the LTE HeNB have same power consumption rate, *Scenario 3, 4, 5* show same power consumption.

The throughputs of diversity mode are shown in Fig. 4. The throughputs of *Scenario 1, 2* are drastically decreased while the WLANs are selected as access network. The average throughputs of *Scenario 1, 2* are 3.539 Mbps and 3.565 Mbps, respectively. The *Scenario 3* has the lowest throughput because its primary goal is not a high throughput but a low cost. The average throughput of the *Scenario 3* is 1.487 Mbps. Since the *scenario 4* and the*scenario 5* do not select WLAN networks, they do not suffer severe packet drops in WLAN areas. The average throughputs of *Scenario 4* and *Scenario 5* are 3.923 Mbps and 3.925 Mbps, respectively.

The throughputs of multiplexing mode are shown in Fig. 5. The *Scenario 6* does not suffer severe packet drops in the first WLAN area, because the eNB is selected as a second access network. From 1366 seconds to 1514 seconds, the throughput rises almost twice as much as its last peak, because a multiplexing gain is successfully achieved. The average throughput of the *Scenario 6* is 4.119 Mbps. The throughput of the *Scenario 7* is similar with the *Scenario 5* except that the it rises almost twice as much as its last peak from 1317 seconds to 1564 seconds. And the average throughput of the *Scenario 6* is 4.485 Mbps, which is about 9 percent higher than that of the *Scenario 6*. Figs. 6 and 7 show the cost and the power consumption of multiplexing mode, but they have small differences.

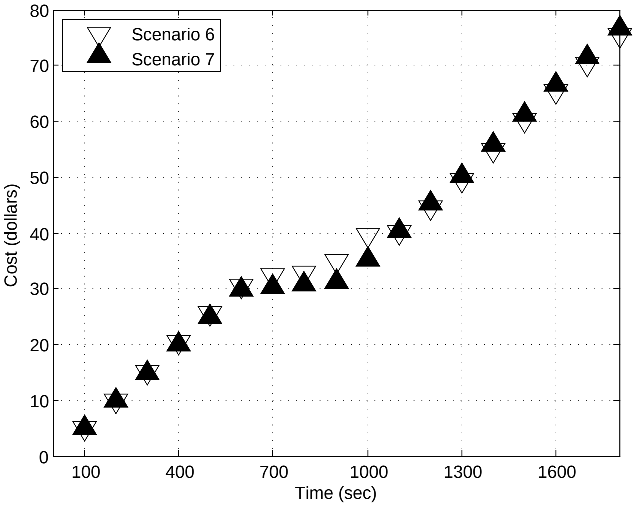

Fig. 6. Cost of Multiplexing Mode

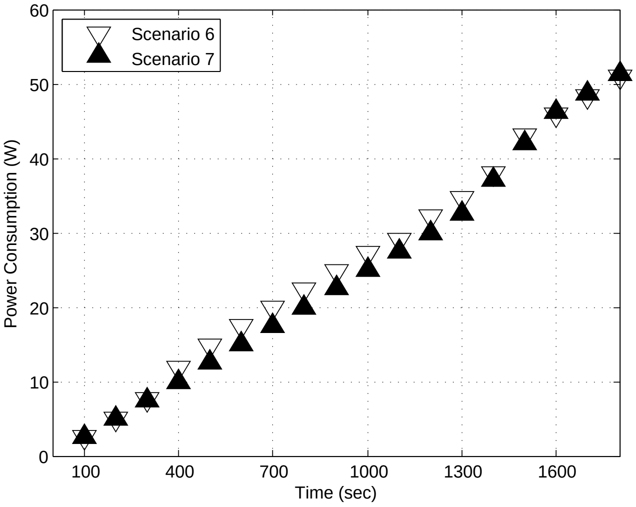

Fig. 7. Power Consumption of Multiplexing Mode

From the simulation results, we can observe that the proposed scheme can achieve higher QoS than conventional SNR based schemes while maintaining similar cost and power consumption. It is shown that the proposed scheme with appropriate weighting factors can achieve a trade-off between the QoS and the cost or the power consumption.

IV. CONCLUSION

In this paper, we proposed a QoS aware network selection scheme which is based on the estimation of the required bandwidth ratio. The QoS requirements of the application services and the condition of wireless channel can be reflected in network selection by employing the required bandwidth ratio as one of the attributes. The proposed scheme also support multi-connection selection considering user preferences. The simulation results have shown that the proposed network selection scheme can achieve a trade-off between the QoS and the cost or the power consumption. Therefore, the proposed scheme can provide the users with an efficient way to configure network selection strategy according to the user preference. In addition, required bandwidth ratio can be used in other MADM-based network selection algorithms.

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