Multi-radio access based bandwidth allocation strategy for video communication in heterogeneous wireless networks

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Abstract

In order to make full use of the radio resource of heterogeneous wireless networks (HWNs) and promote the quality of service (QoS) of multi-homing users for video communication, a bandwidth allocation algorithm based on multi-radio access is proposed in this paper. The proposed algorithm adopts an improved distributed common radio resource management (DCRRM) model which can reduce the signaling overhead sufficiently. This scheme can be divided into two phases. In the first phase, candidate network set of each user is obtained according to the received signal strength (RSS). And the simple additive weighted (SAW) method is employed to determine the active network set. In the second phase, the utility optimization problem is formulated by linear combining of the video communication satisfaction model, cost model and energy efficiency model. And finding the optimal bandwidth allocation scheme with Lagrange multiplier method and Karush-Kuhn-Tucker (KKT) conditions. Simulation results show that the proposed algorithm promotes the network load performances and guarantees that users obtain the best joint utility under current situation.

Keywords video communication, heterogeneous wireless networks, joint utility, energy efficiency, radio resource management

1 Introduction

With the rapid development of radio access technology and the popularity of intelligent mobile terminals, video communication in wireless communication system has gained an increasing interesting among various applications. On the other hand, although there is a fierce competition among different network providers, the next generation networks are imaged as the integrated network where these wireless networks will coexist due to their complementary characteristics. Therefore, the proper network selection method and effective resource allocation scheme are quite important for making full use of the integrated radio resource and satisfying user’s demands well.

Radio resource allocation in HWNs has been studied in several works during the past few years. In Ref. [1], the authors present a network selection algorithm based on multiple attribute decision making (MADM) method to maximize users’ utility. In that study, fuzzy technique for order preference by similarity to an ideal solution (TOPSIS) is adopted to determine the attribute weights. Another MADM based network selection scheme combining RSS, signal to interference ratio (SIR) and bit error rate (BER) is proposed in Ref. [2]. In Ref. [3], Yan et al. put forward a network selection algorithm based on back propagation (BP) neutral algorithm and fuzzy logical. These mentioned algorithms above are single network selection methods. However, the development of software defined radio technology [4] has significantly improved the processing ability of mobile terminals (MTs). The MTs equipped with multiple interfaces are called multi-mode terminals (MMT), which have the ability to support the same application with improved quality of service by utilizing multiple available wireless networks simultaneously.
Therefore, to explore full utilization of the HWNs, many studies have focused on multi-radio access scheme recently. In Ref. [5], Choi et al. optimize the system throughput under the constraint of maximum total power. However, parallel data transmission consumes an increase amount of energy which contributes to the emission of greenhouse [6]. In Ref. [6], Kim et al. investigate the bandwidth allocation through optimization problem by minimizing the energy consumption for transmitting a bit. Due to the complexity of fractional programming, this problem is simplified by deriving a parametric optimization problem and using a double-loop iteration method to solve the original problem. Even though the previous works promote the QoS significantly, scare study has discussed resource allocation for particular traffic on multi-mode terminals. The QoS of different traffic is various in terms of throughput, packet delay, money cost and etc.

In this paper, we propose a multi-radio access based bandwidth allocation algorithm for video communication in heterogeneous wireless networks. An improved DCRRM model is adopted in this algorithm. In addition, the proposed bandwidth allocation algorithm can be divided into two phases. In the first phase, network candidate sets are determined according to the RSS from all radio access technologies (RATs). SAW method is employed to make a comprehensive evaluation among all candidate networks in terms of network load and cost, and the best one of each kind of radio technology will be added into the active set. In the second phase, joint utility function is established by combining user’s video communication satisfaction, cost and energy efficiency. Under the constraint of maximum bandwidth of each network and video rate demand, the bandwidth allocation optimization problem is solved by Lagrange multiplier method and KKT conditions. Simulation results show that the proposed algorithm promotes performance and guarantees that users obtain the best joint utility on the current condition.

The remainder of this paper is organized as follows. In Sect. 2, we introduce the heterogeneous wireless network model and distributed common radio resource management model. The utility function is established and the optimization problem is solved by using Lagrange multiplier method and KKT conditions in Sect. 3. In Sect. 4, we evaluate the performance of the proposed algorithm and conclude the paper in Sect. 5.

2 System model

2.1 Heterogeneous wireless networks model

As shown in Fig 1, the heterogeneous wireless networks system we considered consists of multiple RATs, such as universal mobile telecommunications system (UMTS) networks, Worldwide Interoperability for microwave access (WiMAX) networks and wireless local area network (WLAN). UMTS networks can support wide coverage and seamless handoff but with low throughput. Compared with UMTS, WiMAX networks provide higher date rate. WLANs provide high throughput and charge a low price, but are effectively only in hotspot areas. Users with multi-model terminals arrive in a Poisson process and each user arrivals with video communication traffic demands. It is assumed that the holding time of each traffic is exponentially distributed.

2.2 Distributed common radio resource management model

The radio resource management (RRM) method in Ref. [7] belongs to centralized control manner, where the RRM entity of each network is responsible for collecting network information reported by MTs periodically including RSS, velocity of terminals, channel condition and etc. What’s more, RRM entities exchange information with CRRM in core networks. The final decision information from CRRM entity is brought to users by RRM entities. Whereas, the heavy signaling exchange between MMTs and networks of centralized radio resource management occupies most network resource and cause access delay. For this reason, the authors in Ref. [8] put forward a distributed radio resource management model, in which each network connects to a local RRM entity that
submits network information to CRRM entity. However, it is high cost for every CRRM entity in charge of only a network. In this study we improve the distributed common radio resource management (DCRRM). The enhanced DCRRM model is shown in Fig. 2. The local radio resource management (LRRM) entity of each network is responsible for gathering network condition information and submitting them to CRRM entities which the LRRM entity belongs to. There are several CRRM entities in charge of different LRRM entities. CRRM entities exchange information periodically so that each of them is aware of all the networks condition. In addition, each mobile terminal (MT) belongs to a local CRRM and reports its video parameters, energy consumption to CRRM when the video communication traffic arrival. The local CRRM entity returns to MTs the policy of resource allocation so that MTs only need to contract to local CRRM entities and reduce signaling overhead and access delay correspondingly.

Fig. 2 Distributed joint radio resource management model

3 Utility optimization based bandwidth allocation strategy for video communication

3.1 Networks selection

It is assumed that there are total $I$ networks marked from 1 to $I$ and divided into $N$ groups according to the radio access technologies they apply. For analysis simplicity, we assume that the networks in this paper operate on different frequency bands so that there is no interference among any two networks. In addition, the multi-mode terminals (MMTs) are equipped with $N$ radio interfaces and each interface matches with a particular kind of networks. Therefore, when there are more than one available networks which use the same technology in the HWNs, it is necessary to select the proper one for every interface. Moreover, each interface can establish data transmission path independently and there is no interference between any two interfaces because of their non-overlapping channels.

1) Candidate network set determination

According to the channel propagation model in Ref. [9], we take large scale fading and shadowing into consideration. The path loss at time $t$ of network $i$ at the distance $d$ is formulated by

$$L_{P_i}(t) = L_{P_i}^0 + 10n_i \log \frac{d}{d_0} + X(\nu, \delta), \quad i = 1, 2, ..., I$$

(1)

where $d_0$ denotes the reference distance, $L_{P_i}^0$ is the path loss of network $i$ at distance $d_0$. The path loss exponent $n_i$ of network $i$ depends on wireless environment. Shadowing model $X(\nu, \delta)$ is a Gaussian random variable with mean $\nu$ and standard deviation $\delta$. Assuming the transmission power of base station $i$ is $P_{t_i}^{bs}$, the received signal strength of MT at the distance of $d$ can be obtained as follows

$$S_{ss}(t) = P_{t_i}^{bs} - L_{P_i}(t), \quad i = 1, 2, ..., I$$

(2)

Based on Shannon expression, the date rate which can be obtained from network $i$ is given by

$$r_i = \rho_i b_i \log \left(1 + \frac{S_{ss}(t)}{N_0}\right), \quad i = 1, 2, ..., I$$

(3)

where $\rho_i$ represents the throughput utilization ratio. The channel bandwidth acquired from network $i$ is expressed as $b_i$ Hz , and $N_0$ is the noise power in additive white Gaussian noise (AWGN) channel.
In order to communicate successfully, received signal strength must go up to the threshold $S_{RSS}^h$. In this paper, MMTs gather RSS from available networks periodically. Then the candidate network set $A_m$ of user $m$ can be formulated as

$$A_m = \{i | S_{RSS}^m(t) > S_{RSS}^h; \quad i \in [1, I]\}$$

(4)

2) Active networks set determination

Cost and quality of service are two major aspects that users care about. In general, networks like UMTS provided by communication operation enterprises are highly charged, while WLAN are almost free. In addition, network load condition is related to the resource that users can obtain and the performance of pack delay and packet lost. In this paper, we take into account the network load and charge, and the SAW [10] method is adopted to select networks for each interfaces.

In Eq. (4), we have determined the candidate network set $A_m$ of multi-mode terminal $m$. The networks in $A_m$ can be classified into $N$ categories based on the radio access technology. Here we take $A_{m_l}, \quad l \in [1, 2, ..., N]$ to present the candidate networks sets of each types networks respectively. Each interface of MMT can only connect to one network, so it’s significant to select the best one. All of the selected networks compose active network set $S_{AC_m}$.

In this paper, SAW method is adopted to help users to select the best network from each candidate network subsets. Attributes value and their weights play an important role in SAW method. We take cost and network load balance into consideration. On one hand, attributes can be classified into beneficial attributes and cost attributes. On the other hand, for the comparison of attributes of different values and different units of measurement, normalization processing is necessary. It is supposed that $k = 1, 2$ represent cost and load [7], respectively. We utilize the linear proportion method (LPM) to normalize network attributes as in Ref. [11]

$$y_{i,j} = \frac{x_{i,j}}{x_{i,k}} \quad \eta \leq i \leq N$$

(5)

where $x_{i,j}$ and $y_{i,j}$ represent the real value and normalized value of attribute $k$ of network $i$ in candidate subset $l$, respectively. $x_{i,k}^{\min} = \min_{m} x_{i,k} \neq 0$ represents the minimum value of attribute $k$. Assuming that the attributes weight are defined as $w_i$ and $w_j$, the networks in candidate subset $l$ with the highest score according to SAW can be added into active networks set $S_{AC_m}$

$$S'_{m_l} = \sum_{l=1}^{N} w_i y'_{i,l}; \quad l = 1, 2, ..., N$$

(6)

$$S_{AC_m} = \{ i' | i' = \arg \max S'_{i_l}; \quad l = 1, 2, ..., N \}$$

(7)

where $i'$ represents the serial number of selected network.

3.2 Bandwidth allocation scheme based on utility function

The network selection processing helps users choose a best network from each kind of RAT and connect to all the selected networks simultaneously. Then the most important issue is to allocate the bandwidth resource properly.

It has been estimated that mobile date traffic that comes from video streaming will be more than 65% by the end of year 2015 [12]. The increasing amount of video communication traffic brings a great challenge to networks which are subjected to the limited wireless spectrum resource. In general, video contents contain more information than other traffic streaming. Therefore, video compression and video coding before transmission is essential. The distortion caused by compression and coding should not be too serious to satisfy user’s request. In this paper, we use distortion-rate (DR) model [13] as follows

$$D = \alpha e^{-\beta R}; \quad \alpha > 0, \beta > 0$$

(8)

where $D$ represents the distortion of video measured by the mean square error (MSE) method. $\alpha$ and $\beta$ are video parameters determined by the video content and date rate of the video stream is denoted by $R$. Generally speaking, the peak signal to noise ratio (PSNR) is more an objective measure than MSE for video quality. The relationship between distortion $D$ and PSNR $\eta$ is defined as follows

$$\eta = 10 \log \left( \frac{255^2}{D} \right)$$

(9)

From Eq. (2) we can acquire that PSNR is an inverse proportion to $D$. The higher PSNR value means better QoS, but leads to much resource consumption and money cost. In fact, the human visual system is sensible to picture quality change at low SNR while a small enhancement in high SNR condition is of no significance [14]. Therefore, the second derivative of video satisfaction function about PSNR ought to be negative

$$G_v = \ln \eta = \ln \left( 10 \log \frac{255^2}{D} \right) = \ln(\eta + \beta R)$$

(10)

where $\gamma = 2 \ln 255 - \ln \alpha$, $G_v$ represents video satisfaction.
During video transmission, video quality will increase when users acquire more network resource. But the difference of video content leads to different bandwidth requirement. Each video stream is assumed to elastic between maximum rate \( R^\text{max} \) and minimum rate \( R^\text{min} \). Only when the total available bandwidth of networks larger than inferior limit can user communicate successfully. Therefore, the date rate ought to meet the condition as follows

\[
R^\text{min} \leq R \leq R^\text{max} \tag{11}
\]

For video communication, distortion of video picture is closely related to users’ satisfaction. The video satisfaction model is defined in Eq. (10). The total expense depends on the bandwidth allocated from networks and network price. For the sake of simple, the cost model is given as

\[
G_c = \sum_{\alpha \in \mathcal{S}_c} c^\alpha r_m^\alpha \tag{12}
\]

where \( G_c \) is the total expense. \( \alpha \) represents the serial number of selected network. \( r_m^\alpha \) is the date rate obtained from network \( \alpha \).

In spite of the benefit from multi-homing date transmission, using multiple radio interfaces leads to high energy consumption. How to make effective use of the limit batter energy of MMTs is also studied in this work. In order to ensure a fixed received power \( P_{t}^{\text{tho}} \) needed by RAT, the transmission power \( P_m^\alpha \) of MMT \( m \) at the distance \( d \) is derived as

\[
P_{m,i}^\alpha(t) = P_{t}^{\text{tho}} + L_n(t) \tag{13}
\]

where the path loss \( L_n(t) \) is denoted in Eq. (4). Thus, given the fixed power consumption of transmitting and receiving \( P_c^\alpha \) and \( P_c^{\alpha'} \), the total power consumption for MMTs to connect to network \( i \) is given by

\[
P_c^\alpha(t) = P_{m,i}^\alpha(t) + P_c^{\alpha'} + P_c^{\alpha''} \tag{14}
\]

The energy efficiency model is expressed as

\[
G_e = \sum_{\alpha \in \mathcal{S}_c} r_m^\alpha \tag{15}
\]

To minimize the costs and maximize the benefits simultaneously, the resource allocation model based on multi-radio access ought to be the weighted linear combination of both benefit and cost

\[
\max F(r_m) = a_1 G_e + a_2 G_c - a_3 G_s - a_4 r_m^\alpha ; \ a_1, a_2, a_3, a_4 \geq 0 \tag{16}
\]

where \( a_1, a_2 \) and \( a_3 \) are the parameters of video satisfaction model, energy efficiency model and expense model, respectively. Vector \( r_m = [r_m^1, r_m^2, ..., r_m^\alpha] \) represents the acquired date rate of user \( m \) from network \( i \). Therefore the resource allocation problem for video communication is given by

\[
\max F(r_m) = \max \left\{ a_1 \ln \left( \gamma + \beta_m \left( \sum_{\alpha \in \mathcal{S}_c} r_m^\alpha \right) \right) + a_2 \sum_{\alpha \in \mathcal{S}_c} \frac{r_m^\alpha}{P_c^{\alpha'}} - a_3 \left( \sum_{\alpha \in \mathcal{S}_c} r_m^\alpha c^\alpha \right) \right\} \tag{17}
\]

s.t.

\[
S_1: R_m^\text{min} \leq \sum_{\alpha \in \mathcal{S}_c} r_m^\alpha \leq R_m^\text{max} \\
S_2: 0 \leq r_m^\alpha \leq T_m^{\text{max}}
\]

where \( S_1 \) is video stream date rate constraint and \( S_2 \) is the top date rate \( T_m^{\text{max}} \) which can be acquired from networks. User’s session request will be rejected when there are no sufficient resources available.

### 3.3 Optimization problem solving

It is proved that the joint optimization problem is convex by taking first-order and second-order derivation on \( r_m \), which means that the optimal solution can be derived. What’s more, the local optimal solution is also the global optimal solution [8].

The global optimize solution can be achieved by formulating the following Lagrange function

\[
L(r_m, \lambda_1, \lambda_2, \mu) = a_1 \ln \left( \gamma + \beta_m \left( \sum_{\alpha \in \mathcal{S}_c} r_m^\alpha \right) \right) + a_2 \sum_{\alpha \in \mathcal{S}_c} \frac{r_m^\alpha}{P_c^{\alpha'}} - a_3 \left( \sum_{\alpha \in \mathcal{S}_c} r_m^\alpha c^\alpha \right) + \lambda_1 \left( \sum_{\alpha \in \mathcal{S}_c} r_m^\alpha - R_m^\text{min} \right) + \lambda_2 \left( R_m^\text{max} - \sum_{\alpha \in \mathcal{S}_c} r_m^\alpha \right) + \sum_{\alpha \in \mathcal{S}_c} \mu(r_m^\alpha)
\]

where \( \lambda_1, \lambda_2 \geq 0 \) are the Lagrange multipliers of video stream date rate constraint, and \( \mu = [\mu_1, \mu_2, ..., \mu_\alpha] \geq 0 \) is Lagrange multiplier vector of network available constraints. We can have the KKT conditions by taking derivative with respect to each multiplier

\[
\frac{\partial L}{\partial r_m^\alpha} = \frac{a_1 \beta_m}{\gamma + \beta_m \sum_{\alpha \in \mathcal{S}_c} r_m^\alpha} - \frac{a_2}{P_c^{\alpha'}} - a_3 c^\alpha + \lambda_1 - \sum_{\alpha \in \mathcal{S}_c} \mu = 0 \\
\lambda_1 \left( \sum_{\alpha \in \mathcal{S}_c} r_m^\alpha - R_m^\text{min} \right) = 0 \\
\lambda_2 \left( R_m^\text{max} - \sum_{\alpha \in \mathcal{S}_c} r_m^\alpha \right) = 0 \\
(r_m^\alpha - T_m^{\text{max}}) = 0 ; \ i \in \mathcal{S}_c
\]

(19)
The optimal date rate of MMT can be obtained as

\[ r_m^{opt} = \frac{\lambda_i}{\sum_{\omega_\omega} \mu_\omega + \lambda_2 - \lambda_1 + a_1 c_m - \frac{a_3}{P} \sum_{\omega_\omega} r_m^\omega} - \frac{\gamma}{\sum_{\omega_\omega} r_m^\omega} \] \tag{20}

where \( x^\omega = \max(0, x) \). From Eq. (20) and transformation form of Shannon theory, the channel bandwidth acquired from network \( i \) of MMT \( m \) is as follows:

\[ b_m = \rho \left( \frac{S_i^{RIS}}{1 + \frac{N_i}{S_i^{RSS}}} \right) \] \tag{21}

The Lagrange multipliers are updated as follows:

\[ \lambda_1(T+1) = \lambda_1(T) - \theta_1(T) \left( \sum_{i=1}^T r_m^\omega - R_m^\omega \right) \] \tag{22}
\[ \lambda_2(T+1) = \lambda_2(T) - \theta_2(T) \left( R_m^\omega - \sum_{i=1}^T r_m^\omega \right) \] \tag{23}
\[ \mu_i(T+1) = [\mu_i(T) - \theta_i(T)(r_m^\omega - r_m^\omega)]; \quad i \in [1, I] \] \tag{24}

where \( T \) is the iteration times, \( \theta_1(T) \) and \( \theta_2(T) \) are the iteration step length of multipliers respectively, which satisfy the convergence condition [15].

Through iteration using Eqs. (20)–(24), we can obtain the optimal solution until all of the multipliers change to 0, and the utility to be maximum. In addition, the acquired bandwidths of each user are in different frequency bands, so there is no interference among users. What’s more, traffics are blocked if there are no sufficient radio resources left in all selected networks.

The detailed solution and procedures of the proposed algorithm are as follows

**Step 1** MMTs decide the candidate network set \( A_m \) according to the received signaling strength and classified \( A_m \) into different subsets \( A_m \) based on the radio access technologies.

**Step 2** MMTs evaluate the networks in each candidate subsets according to SAW method combining network cost and load access to the best performed networks.

**Step 3** The video communication satisfaction model \( G_c \), cost model \( G_r \), and energy efficiency \( G_e \) model are built according to formula Eqs. (10), (12) and (15).

**Step 4** Formulate the user’s utility function as an optimization problem which combines the three models mention in Step 3 and solves the problem as Algorithm 1.

**Algorithm 1** Resource allocation algorithm

1: Initialize \( \lambda_1(0), \lambda_2(0), \mu(0) \), \( q(0) \leftarrow 0, T \leftarrow 0 \);
2: Find \( r[T] \) based on Eq. (20);
3: Update \( \lambda_1[T+1], \lambda_2[T+1], \mu[T+1] \) from Eqs. (22)–(24);
4: for \( i = 1 \) to \( I \) do;
5: if \( \sum_{\omega_\omega} b_m^\omega > B \) then \( b_m^\omega \leftarrow 0 \);
6: end for;
7: \( q[T] \leftarrow L(\lambda_1[T], \lambda_2[T], \mu[T]) \);
8: if \( |q[T] - q[T-1]| < \epsilon \) then \( r^* \leftarrow r[T] \);
9: else \( T \leftarrow T + 1 \), go to step 2.

4 **Simulation results and discussion**

We evaluate the performance of the proposed algorithm in this paper by simulation with software Matlab 2012a. There are three UMTS networks, three WiMAX networks and eight WLANs located in the area as shown in Fig. 1.

<table>
<thead>
<tr>
<th>Network</th>
<th>BS location</th>
<th>Cost/(RMB kbit^-1 s)</th>
<th>Coverage/m</th>
<th>Bandwidth/kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>UMTS_1</td>
<td>(0, 0)</td>
<td>0.15</td>
<td>3 000</td>
<td>100</td>
</tr>
<tr>
<td>UMTS_2</td>
<td>(500, 0)</td>
<td>0.154</td>
<td>3 000</td>
<td>100</td>
</tr>
<tr>
<td>UMTS_3</td>
<td>(0, 500)</td>
<td>0.153</td>
<td>3 000</td>
<td>100</td>
</tr>
<tr>
<td>WiMAX_1</td>
<td>(0, 0)</td>
<td>0.13</td>
<td>1 500</td>
<td>255</td>
</tr>
<tr>
<td>WiMAX_2</td>
<td>(0, 500)</td>
<td>0.135</td>
<td>1 500</td>
<td>255</td>
</tr>
<tr>
<td>WiMAX_3</td>
<td>(0, 500)</td>
<td>0.133</td>
<td>1 500</td>
<td>255</td>
</tr>
<tr>
<td>WLANs</td>
<td>Random</td>
<td>0.09–0.11</td>
<td>100</td>
<td>500</td>
</tr>
</tbody>
</table>

The parameters of wireless channel propagation for simulation are shown in Table 2 [16]. And other parameters are set as follows, shadow fading with mean \( \nu = 0 \) and standard deviation \( \delta = 3 \) dB, noise power \( N_0 = 4 \times 10^{-11} \) W, reference distance \( d_0 = 1 \) m, parameters in joint utility optimization model are \( a_1 = 3, a_2 = a_3 = 1.5 \). The fixed receiving power and transmission power of each RAT are \[22, 24, 27\] mW and \[35, 37, 45\] mW. In addition, the video content is selected randomly from the parameters shown in Table 3. The resource allocation algorithm will be initiated once user arrives, and does not change during the holding time.
Table 2  Propagation model parameters in Ref. [16]

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>UMTS</th>
<th>WiMAX</th>
<th>WLAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{b0}$</td>
<td>dBm</td>
<td>30</td>
<td>27</td>
<td>20</td>
</tr>
<tr>
<td>$n_i$</td>
<td></td>
<td>3.5</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>$\rho_i$</td>
<td></td>
<td>0.85</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>$S_{\text{sys}}$</td>
<td>dBm</td>
<td>$-110$</td>
<td>$-108$</td>
<td>$-87$</td>
</tr>
<tr>
<td>$L_{\text{sys}}$</td>
<td>dB</td>
<td>5</td>
<td>27</td>
<td>8</td>
</tr>
<tr>
<td>$P_{\text{req}}$</td>
<td>dBm</td>
<td>$-62$</td>
<td>$-61$</td>
<td>$-57$</td>
</tr>
</tbody>
</table>

Table 3  Video parameters in Ref. [17]

<table>
<thead>
<tr>
<th>Video</th>
<th>$\alpha$</th>
<th>$\beta$</th>
<th>$R_{\text{max}}$ / (kbit s$^{-1}$)</th>
<th>$R_{\text{req}}$ / (kbit s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12 570</td>
<td>1.301</td>
<td>57.179 3</td>
<td>1 813.265</td>
</tr>
<tr>
<td>2</td>
<td>13 710</td>
<td>1.441</td>
<td>40.9478</td>
<td>1 449.646</td>
</tr>
<tr>
<td>3</td>
<td>285 880</td>
<td>2.413</td>
<td>32.3378</td>
<td>1 135.305</td>
</tr>
<tr>
<td>4</td>
<td>17 140</td>
<td>1.205</td>
<td>101.7666</td>
<td>1 786.538</td>
</tr>
<tr>
<td>5</td>
<td>122 740</td>
<td>1.846</td>
<td>59.4218</td>
<td>1 385.670</td>
</tr>
<tr>
<td>6</td>
<td>115 930</td>
<td>1.394</td>
<td>214.7078</td>
<td>2 556.943</td>
</tr>
<tr>
<td>7</td>
<td>490 430</td>
<td>1.630</td>
<td>239.2394</td>
<td>1 991.028</td>
</tr>
<tr>
<td>8</td>
<td>234 140</td>
<td>1.574</td>
<td>181.3834</td>
<td>2 625.342</td>
</tr>
</tbody>
</table>

In order to evaluate the multi-radio access performances of the proposed algorithm, comparisons are made between the proposed algorithm and single-network selection method. In single-network access method, terminals select the networks with the highest score from all candidate networks by means of SAW and request proper bandwidth from the target networks by maximizing the joint utility.

Figs. 3–6 show the joint utility, user video satisfaction, block rate and energy efficiency for the proposed method and the single-network access method, respectively. In this part, we assume that the average holding time of each traffic is 200 s. It is observed that with the increase of the user arrival rate, the performances of both methods are all decrease, especially at the beginning period. The reason is that the available bandwidth of networks reduce sharply with the increase of arrival rate of users. That is to say, there are no sufficient resources for the latter arrived traffics or even lead to block. Therefore, the joint utility and video satisfaction inch down. In addition, it is observed from Figs. 3–5 that the proposed scheme in this paper can perform better than the single-access network method. As mentioned before, in single-access method, users can have an access to the best one based on SAW and this network ought to be the selected in multi-radio access method. Therefore, the single-access scheme is only a part of our algorithm and the proposed method can make full use of all the accessible.

While, it is observed from Fig. 7 that the blocking performance is inferior to the single-access method a little. The reason is that in the proposed algorithm users can acquire more bandwidth from multiple networks to enhance the satisfaction degree of video communication so there is less resource remaining for the later arrived users or even lead to user block. Comprehensively considered, the proposed algorithm improves performances in most aspects and performs better than the single-access method.
In this section, we study the effect of load balancing strategy in network selection phase, which is shown in Figs. 7–10. In random selection algorithm, users select a network from each candidate network subset randomly without caring of the target networks load condition. Figs. 7–9 depict the joint utility, video utility and energy efficiency with respect to the arrival rate of users, respectively. It is the same as in Fig. 3 in tendency. Figures show that the proposed algorithm outperforms the random access method for the reason that in random selection algorithm users may select the overload networks so that users cannot acquire adequate network resource as well as better utility. And Fig. 10 depicts the total blocking rate with respect to user arrival rate. It is observed that along with the increase of arrival rate, the blocking rate increases correspondingly. But the proposed algorithm in this paper outperforms the random algorithm adequately. Reasons are that random access makes it more possible for users to access an overload networks that cannot support sufficient resources for them. With the increase of arrival rate, this probability increases correspondingly.

5 Conclusions

In this paper, we put forward a multi-radio access based bandwidth allocation algorithm for video communication in heterogeneous wireless networks. An improved distributed common radio resource allocation model is adopted for reducing the signaling overhead and access delay. The proposed scheme consists of two phases, namely networks selection phase and bandwidth allocation phase. In the first phase, MMTs decide the candidate set
according to the RSS and select some networks based on SAW method. In the second phase, we formulate the video streaming allocation scheme as optimization problem for maximizing the joint utility and drive its solution with the Lagrange multiplier method and KKT conditions. Simulation results show that the proposed algorithm maximizes the joint utility, enhances the users’ video satisfaction and guarantees load balancing efficiently.

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