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A Simple and Robust Vertical Handoff Algorithm for Heterogeneous Wireless Mobile Networks

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Abstract Wireless networking is becoming an increasingly important and popular way of providing global information access to users on the move. One of the main challenges for seamless mobility is the availability of simple and robust vertical handoff algorithms, which allow a mobile node to roam among heterogeneous wireless networks. In this paper, motivated by the facts that vertical handoff procedure is done on mobile nodes and battery power may be one crucial parameter for certain mobile nodes, a simple and robust two-step vertical handoff decision algorithm is proposed for heterogeneous wireless mobile networks. To the best of our knowledge, this is the first vertical handoff algorithm that takes the classification of mobile nodes into consideration, one is resource-poor mobile nodes, and the other is resource-rich mobile nodes. This new feature makes it more applicable in the real world. In addition, dynamic new call blocking probability is firstly introduced by this paper to make handoff decision for wireless networks. The experiment results have shown that the proposed algorithm outperforms traditional algorithms in bandwidth utilization, handoff dropping rate and handoff rate.

Keywords Vertical handoff · New call blocking probability · Heterogeneous wireless mobile networks

1 Introduction

With rapid development and deployment of wireless technologies, we are faced with the challenge of combining a diverse number of wireless networks. The fourth generation (4G)

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of mobile communication networks is expected to integrate a potentially large number of heterogeneous wireless technologies in what could be considered a huge step forward toward universal seamless access. One of the main challenges for seamless mobility is the availability of simple and efficient vertical (intersystem) handoff (i.e., handover) schemes, which is the decision for a mobile node (e.g., notebook computer, PDA and smart phone) to handoff between different types of networks, such as satellite, cellular, wireless wide area network (WWAN) and wireless local area networks (WLANs) [1]. Vertical handoff schemes will play a major role in the IEEE 802.21 standard and shall pave the road for emergence of 4G overlay multi-network environment. The preferred vertical handoff can enable mobile nodes (terminals) to move freely across heterogeneous wireless mobile networks with the quality-of-service (QoS) requirements satisfied. In the following, the detailed information about vertical handoff is given.

Vertical handoff is defined as the handoff between two base stations (BSs) with different wireless network technologies. In general, the vertical handoff process is divided into three steps. First, a mobile node must know which wireless systems are reachable. This step is called system discovery. The next step is handoff decision, in which the mobile node evaluates vertical handoff parameters associated with a new wireless system (network) to make handoff decision. If the mobile node decides to handoff to other network, the last step will proceed. The last step is handoff execution. If the mobile node decides to perform vertical handoff, it executes the vertical handoff procedure to be associated with a new wireless system. Note that a handoff execution means a successful handoff to the other network. We mainly concentrate on the second step in this paper. There are three strategies for detecting the need for handoff: mobile-controlled handoff (MCHO), network-controlled handoff (NCHO), and mobile-assisted handoff (MAHO). MCHO is used in IEEE 802.11 WLAN networks, where a mobile node continuously monitors the signal of an access point (AP) and initiates the handoff procedure when some handoff criteria are met. Since only mobile nodes have the knowledge about what kind of network interfaces they are equipped, MCHO is more suitable for vertical handoff [2]. Due to limited resources of mobile nodes, it is clear that low power consumption is a primary design goal for vertical handoff decision.

In vertical handoffs, many network characteristics have an effect on whether or not a handoff should take place. These include cost of service, security, power consumption, network conditions, and network performance. For more information about these parameters, the reader is referred to [1]. Up to now, many methodologies have been used on vertical handoff, such as policy-enabled schemes (e.g. [3–5]), fuzzy logic (e.g. [6,7]), neural networks concepts (e.g. [8–10]), pattern recognition (e.g. [11,12]), etc. Although some of these methods are quite successful, they are not particularly suitable for real-time applications such as voice over internet protocol (VoIP), since the reliability of them usually depends on complex procedure. Furthermore, as mentioned above, vertical handoff is often implemented on resource-limited mobile nodes. Therefore, complex handoff decision procedure is not fit for real world applications. In addition, all existing works do not consider network traffic load in the handoff decision procedure. Besides, most of the previous works make handoff decision based on thresholds of received signal strength (RSS) but yield serious ping-pong effect when a mobile node moves around the overlay area of several heterogeneous wireless networks. The ping-pong effect causes unnecessary handoff and brings some weaknesses, including low network throughput, long handoff delay, and high dropping probability.

Available bandwidth is used to indicate network conditions and is a major factor, especially for voice and video traffic. There have been many works focusing on available bandwidth based vertical handoff support (e.g. [1,13–16]).

In addition, two of the most important indexes for QoS monitoring are the new call blocking probability (NCBP) and the handoff call dropping probability [i.e., handoff dropping rate (HDR)] [17]. The detailed description of the NCBP and the HDR are as follows. A new call is initiated when a user requests a new connection, while a handoff call occurs when an active user moves from one network to another. Thus, NCBP is the probability of a new arriving call being rejected while HDR is the probability that a handoff attempt fails. In mobile communication networks, limiting HDR within a pre-specified target value is a very important QoS issue because mobile nodes should be able to maintain ongoing sessions even during their handoff. In general, handoff dropping is more objectionable than new call blocking.

Motivated by the facts that vertical handoff procedure is done on mobile nodes and battery power may be one crucial parameter for certain mobile nodes, we propose a simple and robust two-step vertical handoff decision algorithm for heterogeneous wireless mobile networks in this paper. First step describes the quick evaluation method for the pre-handoff decision. Second step presents the handoff decision function for handoff execution. For resource-poor mobile nodes, vertical handoff decision only considers the first step. On the other hand, for resource-rich mobile nodes, vertical handoff decision would consider both steps. Obviously, the proposed algorithm aims at achieving a trade-off in achieving optimal target network choice and low-power consumption for vertical handoff decision. Therefore, it is simpler and more robust than the well known vertical handoff algorithms (e.g. [1,3–12]). To the best of our knowledge, this is first developed vertical handoff algorithm that takes the resources of mobile nodes into consideration, one is resource-poor mobile nodes, and the other is resource-rich mobile nodes. In addition, we first observe that handoff decision can be made based on the comparison of the dynamic new call blocking probability (DNCBP) of each network. The detailed information about the DNCBP is described in Sect. 3.3. DNCBP can be used to indicate network traffic load. In other words, the larger the DNCBP of a particular network is, the heavier the network traffic load of the particular network is. In order to increase bandwidth utilization rate (i.e., network throughout) and lower the values of the NCBP and the HDR, we should prefer to handoff to the network with lower DNCBP. With this motivation, in the second step of our proposed algorithm, we present a novel vertical handoff decision function based the DNCBP for heterogeneous wireless mobile networks. Compared with other network characteristics (e.g., available bandwidth), DNCBP can help in determining the potential service quality of a candidate network more efficiently. Besides, by introducing the DNCBP, the proposed scheme can balance network load in all networks. This helps to reduce the probability of new call dropping. This new feature makes the proposed handoff decision algorithm more efficient. To the best of our knowledge, it is the first time that DNCBP has been introduced to make handoff decision for heterogeneous wireless networks in the literature. In addition, since our proposed decision scheme is so simple, the vertical handoff is fast. Further, mobile nodes do not experience service degradation or interruption. Finally, the experiment results have shown the proposed algorithm outperforms the traditional approach of (e.g. [1,18]) in bandwidth utilization rate, handoff dropping rate and handoff rate.

The reminder of this paper is organized as follows: In Sect. 2, we briefly introduce the traditional approach. Some background knowledges of this paper are provided in Sect. 3, including network model, new call blocking probability and dynamic new call blocking probability. The proposed handoff decision algorithm is given in Sect. 4, followed by performance evaluation of the proposed algorithm in Sect. 5. Finally, we draw our conclusions in Sect. 6.

2 The Traditional Approach

The traditional algorithm is given in [1,18]. As a mobile node roams across different networks, the vertical handoff decision function (VHDF) is evaluated for all accessible networks. The network with the highest calculated value for VHDF is the most desirable for the user based on specified preferences. The network quality Q_i, which provides a measure of the appropriateness of a certain network n_i, is measured via the function

$$Q_i = f\left(\frac{1}{C_i}, S_i, \frac{1}{P_i}, D_i, F_i\right) \tag{1}$$

Where C, S, P, D, F are the cost of service, security, power consumption, network conditions, network performance, respectively.

The above algorithm can be simplified as follows. The user's preference is to get the highest possible QoS by receiving the maximum amount of bandwidth, regardless of other factors such as usage cost, security, and power consumption. Therefore, the user sets the VHDF to

$$Q_i = f\left(\left(0 \times \frac{1}{C_i}\right), (0 \times S_i), \left(0 \times \frac{1}{P_i}\right), (1 \times D_i), (0 \times F_i)\right) \tag{2}$$

In other words, the user sets the VHDF to

$$Q_i = b_i \tag{3}$$

The traditional approach is also described as follows. A mobile node calculates the current available bandwidth for its current network and for the newly detected networks. The network with the highest available bandwidth is the preferred network. More specifically, if there is a newly detected network having a higher available bandwidth, vertical handoff takes place. Otherwise, the mobile node remains connected to the current network.

3 Preliminaries

In this section, we introduce the building blocks of the proposed handoff algorithm, which include network model, new call blocking probability and dynamic new call blocking probability.

3.1 Network Model

Without loss of generality, wireless networks under consideration are denoted as $n_i, i = 1, 2, \ldots, N$. For example, there are three available networks, universal mobile telecommunications system (UMTS), WLAN and satellite. Another example is that there are two available networks, WLAN and WWAN. B_i and b_i denote respectively the total bandwidth and current available bandwidth of network n_i. N is the maximum number of considered networks. The technologies to estimate current available bandwidth has been proposed (e.g. [2,14]). And this is beyond our present scope.

3.2 New Call Blocking Probability

For the traffic characteristics, we assume that the bandwidth change process of network n_i is modeled as an $M/M/B_i/B_i$ process. The arrival of requests for channels follows a Poisson distribution with mean λ_i (i.e.; the mean number of request arrivals per unit time is λ_i), where $i = 1, 2, \ldots, N$.The call holding time (CHT) is assumed to follow an exponential distribution with mean $1/\mu_i$ (i.e.; the mean number of calls serviced per unit time is μ_i). Note that in a network with no holding queue, the capacity is equal to the total number of channels. These assumptions are reasonable and used by many researchers (e.g. [1,16,18–20]). In real world, the parameters such as λ_i and μ_i can be properly estimated using some techniques (e.g., exponential averaging computation). Suppose P_i presents the new call blocking probability (i.e., the grade of service) of network n_i. According to the Erlang-B model, the following equation holds:

$$P_i = \frac{\left(\frac{\lambda_i}{\mu_i}\right)^{B_i}}{B_i!}\left(\sum_{n=0}^{B_i}\frac{\left(\frac{\lambda_i}{\mu_i}\right)^n}{n!}\right)^{-1} \tag{4}$$

3.3 Dynamic New Call Blocking Probability

To get the DNCBP of network n_i, we just use b_i to replace B_i in above Eq. (4). Thus, the priority to handoff calls is obtained in a more dynamic manner. And the experiment results have demonstrated that the DNCBP has much better performance than the NCBP. Denote H_i as the DNCBP of network n_i.we can get

$$H_i = \frac{\left(\frac{\lambda_i}{\mu_i}\right)^{b_i}}{b_i!}\left(\sum_{n=0}^{b_i}\frac{\left(\frac{\lambda_i}{\mu_i}\right)^n}{n!}\right)^{-1} \tag{5}$$

4 The Proposed Scheme

In this section, we will present a simple and robust vertical handoff decision algorithm. As mentioned in Sect. 1, vertical handoff procedure is initiated by resource-limited mobile devices. Ideally, there is an inherent trade-off in achieving optimal target network choice and low-power consumption for vertical handoff decision, and we must avoid situations in which one goal is realized at the expense of other. That is, reducing power consumption by keeping vertical handoff decision simple, which results in that the chosen network may not be optimal. Similarly, the optimal target network choice could be achieved by making the handoff decision function complex. But this results in an inordinate waste of power. Thus, in each handoff decision making process, we can face the following question: How does vertical handoff decision process works on resource-poor mobile nodes and resource-rich mobile nodes respectively? To develop a simple and robust handoff decision, a two-step vertical handoff decision algorithm is first presented. Figure 1 depicts the flow diagram for the proposed handoff decision algorithm. The first step describes the quick evaluation method for the pre-handoff decision. The second step presents the handoff decision function for handoff execution. For resource-poor mobile nodes, vertical handoff decision procedure only considers the first step. On the other hand, for resource-rich mobile nodes, vertical handoff

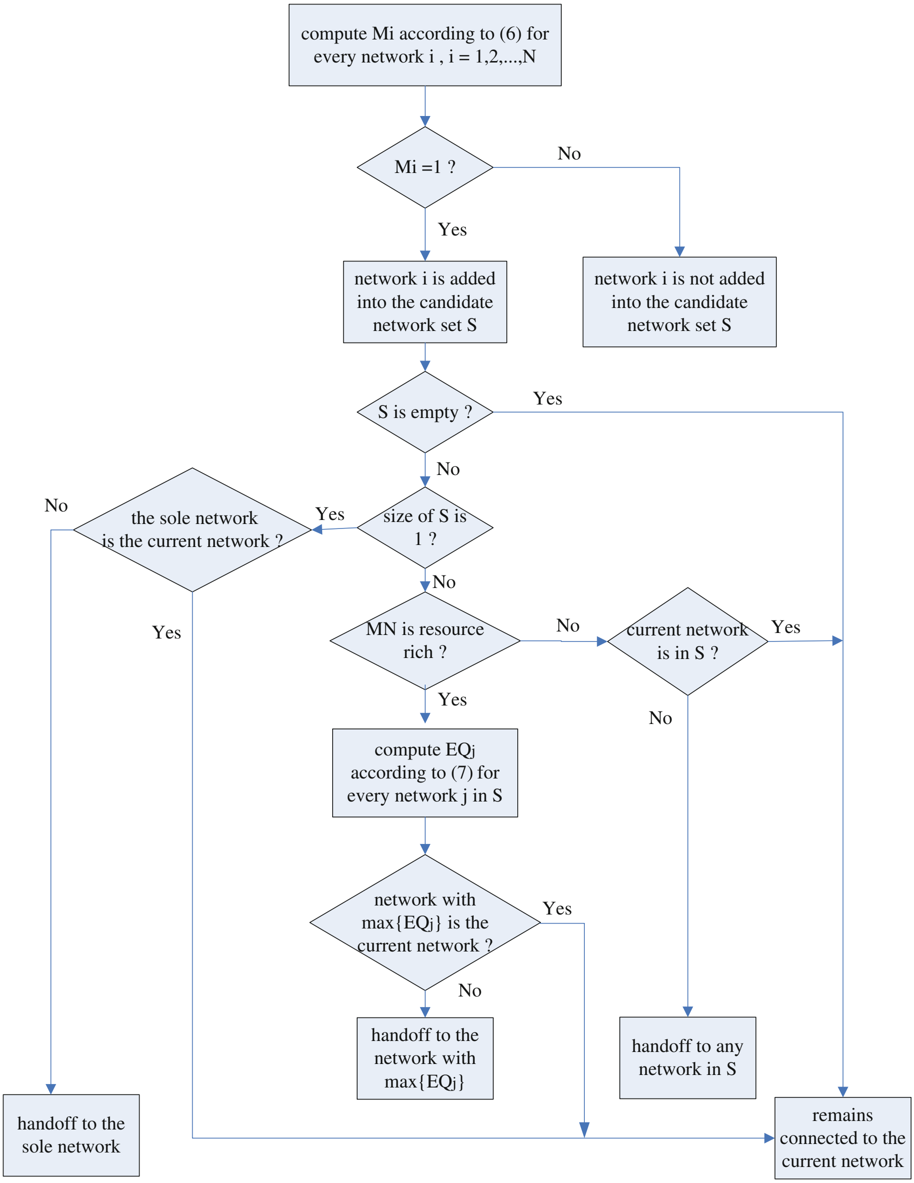

Fig. 1 The proposed handoff decision algorithm

procedure would consider both steps. Obviously, our approach can reduce energy consumption on mobile nodes, especially on low energy mobile nodes. In the following description of the proposed handoff decision algorithm, we consider the scenario where a mobile node (MN) detects more than one available networks and then determines which available network is best suited for data transfer. Here we assume that the number of available networks is N .

4.1 The First Step: Quick Evaluation Method for the Pre-Handoff Decision

Clearly, different classes of services require various combinations of vertical handoff parameters (e.g., reliability, latency, and data rate). Therefore, user's traffic classes (i.e., classes of service, service types) should be considered in the handoff decision. For the traffic classes, we follow the four QoS classes of network applications defined by UMTS [21]. They are conversational class (e.g., voice), streaming class (e.g., streaming video), interactive class (e.g., web browsing) and background class (e.g., telemetry, emails). For example, according to the delay sensitivity characteristics, the first two types are grouped as real time service, while the other two belong to non-real time service. Since real-time service is sensitive to delay, a guaranteed transmission rate is essential. Of course, the division of traffic classes can be made by users.

In vertical handoffs, many network parameters have an effect on whether or not a handoff should take place. The important parameters include quality of service (e.g., handoff delay, available bandwidth), security, power requirements, cost of service, and so on.

In the first step, the pre-handoff decision evaluates whether the minimum guarantee of a user is supported for every network i, $i = 1, 2, \ldots, N$. More specifically, the values of some easy-detected and crucial parameters must be more than the predefined thresholds, respectively.

$$\begin{aligned} M_i = &\, F(b_i - b_{th}) \cdot F(\mathrm{RSS}_i - \mathrm{RSS}_{th}) \cdot F(V_i - V_{th}) \\ &\times F(T_i - T_{th}) \cdot F(P_i - P_{th}) \cdot F(C_i - C_{th}) \end{aligned} \tag{6}$$

Equation (6) represents a minimum guarantee function, which indicates whether the minimum guarantee of MN is supported for every network i. It is aimed at making use of some of the parameters referred in Eq. (6) in order to make a quicker and wiser handoff decision. Here b_i, RSS_i, V_i, T_i, P_i and C_i represent the values of available bandwidth, received signal strength (RSS), velocity, duration, battery power and monetary cost of MN from a particular network i. The duration T_i denotes the estimated time MN will stay in a particular network i, which is predicted by some detailed parameters (e.g., the velocity of MN, the coverage of a particular network i, moving pattern of MN, and the location information of MN). In addition, b_{th}, RSS_{th}, V_{th}, T_{th}, P_{th} and C_{th} are the predefined thresholds of available bandwidth, received signal strength, velocity, duration, battery power and monetary cost to support the requested traffic class (e.g., streaming class, interactive class). The requested traffic class often is the main traffic class or the most important traffic class for MN, which takes up the most throughout. The function $F(.)$ is a unit step function. The unit step function is a discontinuous function whose value is zero for negative argument and one for positive argument. Hence, once there is not less than one parameter value of MN from a particular network i is lower than its threshold, the minimum guarantee function has zero value. In this case, network i is not considered as a target network any more. If the minimum guarantee function value is one for a particular network i, this network will be added to the candidate network set S. Note that the set S is set to be empty at the beginning of every handoff decision. Since Eq. (6) is simple and the parameters from this equation can be estimated quickly, time consumption of the pre-handoff decision is very low. Of course, some parameters can further be omitted according to the context of specific application (e.g., the resource of MN, the availability of some parameters referred above). For example, in some scenarios, since the duration of MN cannot be estimated for some reasons, this parameter has to be omitted.

Obviously, by introducing the duration into the minimum guarantee function, the serious ping-pong effect can be efficiently eliminated. Thus, our approach reduces unnecessary handoffs while increasing network throughput, decreasing handoff delay, and avoiding connection dropping.

In addition, the velocity should be considered in the first step. For example, if MN's speed is over 100 km/h, WLAN cannot support its speed.

Besides, battery power may be a crucial parameter for certain users. For example, when the battery level is low, the user may choose to switch to a network with lower power requirements (i.e., the threshold of battery power), such as an ad hoc Bluetooth network.

After the pre-handoff decision is finished, according to the size of the candidate network set S, the propose decision algorithm generally falls into three cases. One is that the set S is empty, MN remains connected to the current network. Another is that there is only one member in set S. If the sole network is the current network, MN stays in the current network; otherwise, MN decides to perform vertical handoff procedure to be associated with the network. The other is that more than one network have been added into the set S. More specifically, there is more than one network, whose minimum guarantee function value is one. If MN is a resource poor node and the current network is in the set S, MN will remain connected to the current network. If MN is a resource poor node and the current network is not in the set S, MN will handoff to any network included in the set S. If MN is a resource rich node, MN will proceed to the second step.

4.2 The Second Step: Vertical Handoff Decision Function

In this step, an extended vertical handoff decision function (EVHDF) is presented, which is an extended version of VHDF in [1]. EVHDF is used to measure the improvement gained by handing off to a particular network j included in the candidate network set S. Here we assume the size of the candidate network set S is m. It is obvious that m is an integer larger than one. According to Eq. (5), it can be seen that the computation of DNCBP does not only relate to available bandwidth, but also network traffic load. In addition, the DNCBP can be used to indicate network traffic load. Therefore, use of the DNCBP in the EVHDF can be more useful for network load balancing across different networks than other parameters (e.g., available bandwidth). The network with the highest calculated value for EVHDF is the most optimal for MN based on specified preferences. The EVHDF for a particular network j, EQ_j, is defined by:

$$EQ_j = \frac{\omega_C\left(1/C_j\right)}{\max((1/C_1),\ldots,(1/C_m))} + \frac{\omega_S S_j}{\max(S_1,\ldots,S_m)} + \frac{\omega_P P_j}{\max(P_1,\ldots,P_m)} + \frac{\omega_D D_j}{\max(D_1,\ldots,D_m)} + \frac{\omega_F F_j}{\max(F_1,\ldots,F_m)} \tag{7}$$

As described in [1], here ω_C, ω_S, ω_P, ω_D and ω_F are weights for each of the network parameters. The values of these weights are fractions (i.e., they range from 0 to 1). Moreover, all five weights add up to 1. Each weight is proportional to the significance of a parameter to the vertical handoff algorithm. In addition, $C,\ S,\ P,\ D,\ F$ present the cost of service, security, power consumption, network conditions, network performance, respectively. The main difference between EVHDF here and that in [1] is that $D_j = b_j$ in [1] has been replaced with $D_j = \frac{b_j}{H_j}$.

The network with the highest EQ_j is the preferred network. If the preferred network is not the current network, vertical handoff takes places; otherwise, MN remains connected to the current network.

In the next section, the performance of the proposed handoff decision algorithm is analyzed.

5 Performance Evaluation

The performance of the proposed method is evaluated by simulation. To ease our illustration, we just consider the situation in which there are two networks A and B without background traffic. Network A represents a WWAN and has a low bandwidth of 384 kb/s. On the other hand, network B has a higher bandwidth of 1 Mb/s and represents a WLAN. In the experiment, we classify the offered load into "none," "light," "average," "heavy and "oscillating". In addition, the bandwidth requested by every call is constant. Such an input traffic is suitable to model conversational and streaming type of traffic. Since the conversational traffic is a typical traffic class and more vulnerable to handoff (e.g., vertical handoff dropping probability) than the other traffic classes, our experiment focuses on it. The numerical results indicate that performance comparison of traditional approach and our method varies with different offered load. However, note that any other network combination or any other combination of the vertical handoff parameters listed in Sect. 4 can just as easily be substituted in the performance evaluation.

The mobile nodes have two strategies to make handoff decision: One is traditional handoff algorithm given in (e.g. [1,18]). That is, one mobile node prefers to handoff to the network with more available bandwidth. The other is the simple version of our proposed method. More specifically, in the first step, as shown in Eq. (6), we set $M_i = F(b_i - b_{th}) \cdot F(\mathrm{RSS}_i - \mathrm{RSS}_{th}) \cdot F(T_i - T_{th})$. Here the three thresholds b_{th}, RSS_{th} and , T_{th} is constant for every mobile user. In the second step, we set $EQ_j = \frac{D_j}{\max(D_1,\ldots,D_m)}$, where $D_j = \frac{b_j}{H_j}$. Here we assume that all mobile nodes have enough resource to make both steps. Note that the values of the above three thresholds are predefined according to the specific application environment. And our experiment did not focus on any specific traffic class. As mentioned above, it is clear that if the thresholds of the handoff decision parameters are predefined according to a specific traffic class, the performance of our proposed algorithm will be better.

From Fig. 2, it is visible that when the offered load varies, our method always shows the improvement over traditional approach on overall bandwidth utilization (i.e., network throughout). More specifically, in each chosen case, our method increases bandwidth utilization by 2% compared with the traditional approach. Note that overall bandwidth utilization is mainly restricted by pre-specified offered load. Thus, due to the pre-specified offered load, the overall bandwidth utilization improvement brought by our method is significant enough. In this point, the handoff dropping rate is the same as overall bandwidth utilization.

Figure 3 gives the effect of offered load on handoff dropping rate. From Fig. 3, we see that when the offered load varies, our method always outperforms the traditional algorithm on handoff dropping rate. And it reduces handoff dropping rate by up to about 0.176% in individual cases.

Figure 4 shows the result of handoff rate. The handoff rate is the ratio of total number of handoff execution to handoff decision. As described in Sect. 1, a handoff execution means a successful handoff to the other network. In the experiment, we set the number of handoff decision in the traditional approach equals to that in our proposed approach. Obviously, the proposed approach shows that handoff rate is always smaller than that in the traditional approach.

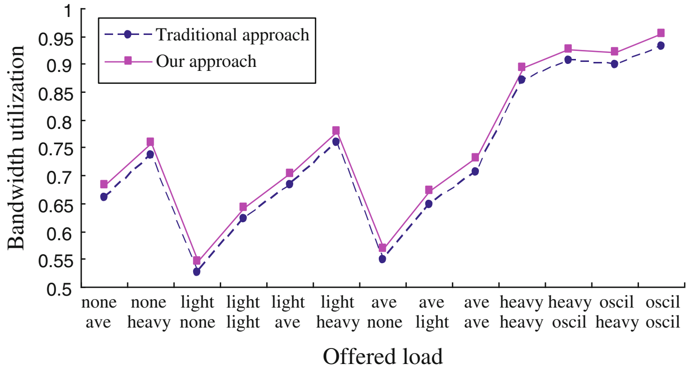

Fig. 2 Impact of offered load on overall bandwidth utilization

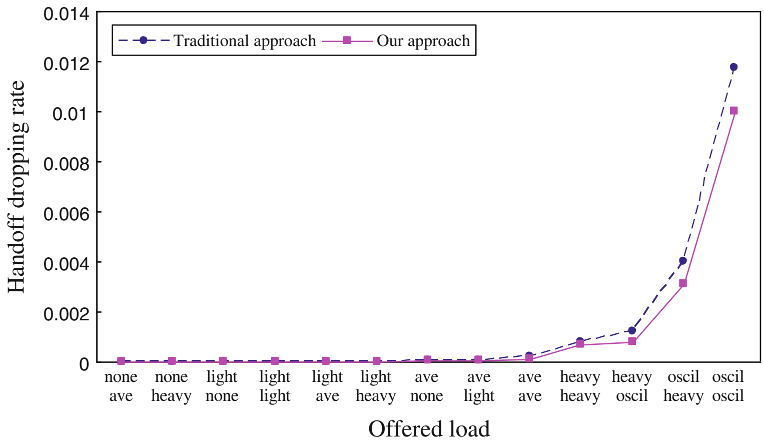

Fig. 3 Impact of offered load on handoff dropping rate

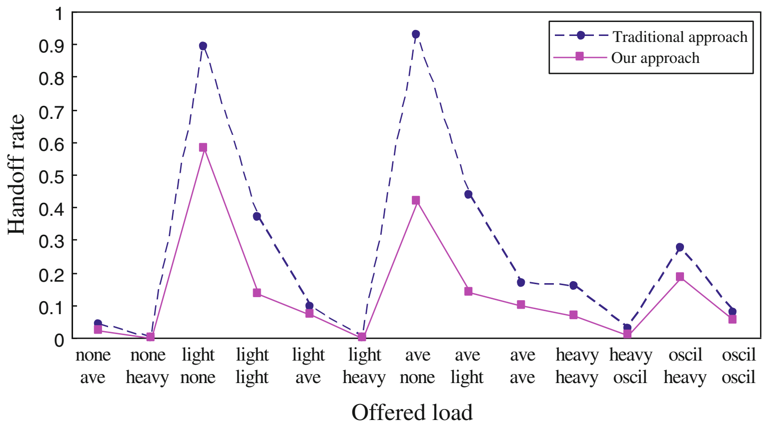

Fig. 4 Impact of offered load on handoff rate

The three improvements mentioned above are due to the ability of our proposed method as follows. Since the duration and the DNCBP are firstly introduced into handoff decision, our scheme considers the offered load and the ping-pong effect. Therefore, our proposed scheme does not only improve the bandwidth utilization rate, but also reduces the number of unnecessary handoffs. Further, as described in Sect. 1, since our approach can efficiently eliminate the ping-pong effect, it can reduce handoff delay, and avoid connection dropping.

6 Conclusion and Future Work

Future wireless networks must be able to coordinate services within a diverse network environment. One of the challenging problems for coordination is vertical handoff decision algorithm. In this paper, we have proposed a simple and robust vertical handoff algorithm. It is the first time that DNCBP is used as a means of making handoff decision. The experimental results have proven that the proposed method outperforms the traditional algorithm in bandwidth utilization rate, handoff dropping rate and handoff rate.

Considering that available bandwidth, DNCBP and RSS may not be enough for QoS, the packet loss rate can be used to enhance our approach in the future. In addition, future work includes reasonable weight selection on vertical handoff decision function.

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