A Software-Defined Network based Vertical Handoff Scheme for Heterogeneous Wireless Networks

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***Abstract*—We propose a novel Quality of Service (QoS) vertical handoff scheme with the support of the Software-Defined Network (SDN) technique for the heterogeneous wireless networks. The proposed scheme solves two important issues of the vertical handoff: *network selection* and *handoff timing*. In this paper, the network selection is formulated as an 0-1 integer programming problem, which maximizes the overall QoS and avoids the network congestion. After the network selection process is finished, a mobile will wait for a time period for implementing the vertical handoff. The selected network should be consistently more appropriate than the current network during the time period, the mobile will transfer its inter-network connection to the selected network. Our proposed scheme ensures that, a mobile will transfer to the most appropriate network at the most appropriate time. Comprehensive simulation has been conducted. It is shown that the proposed scheme reduces the number of vertical handoffs, and maximizes the overall QoS significantly comparing with existing schemes.**

I. Introduction

Heterogeneous wireless networks integrate a variety of wireless techniques to provide ubiquitous services. In the heterogeneous wireless networks, mobiles may need to transfer their inter-network connections from one network to another one. The transferring operation among different kinds of networks is called the vertical handoff [1]. There are two important issues needed to be solved in the vertical handoff. One is to select a network, to which the inter-network connection should be transferred. The other one is to determine the handoff timing, when the inter-network connection transferring should be implemented. The emergence of Software-Defined Network (SDN) technique [2] makes it possible to solve these two issues of the vertical handoff in a novel perspective. SDN is a new networking paradigm, which provides a global centralized control of network devices. In this paper, we make use of this feature of SDN and study the vertical handoff problem in the heterogeneous wireless networks.

Some related work has been conducted in addressing the vertical handoff problem. H. J. Wang et al. [3] proposed a policy-enabled vertical handoff scheme. J. Hou et al. [4] proposed a fuzzy logic based vertical handoff scheme. An interesting scheme is proposed by B. Ciubotaru et al. [5], called Smooth Adaptive Soft Handoff Algorithm (SASHA). In SASHA, a mobile obtains a weighted sum of various network performance parameters together, and calculates the Quality of Service (QoS) values of its available networks. Then, this mobile allocates its traffic according to the QoS values, the higher QoS value the more traffic. As the mobile leaves a network and gets closer to another network, the QoS value of the leaving network gets lower, and the QoS value of the approaching network gets higher. As a result, traffic on the leaving network is transferred to the approaching network gradually. W. Lee et al. [6] carried out research from the aspect of optimization, and proposed an Enhanced Group Handoff Scheme (EGHS). In EGHS, each mobile evaluates its available networks on the remaining bandwidth, the more bandwidth the better. The network selection is formulated as a convex optimization problem. After the network is selected, a mobile transfers its inter-network connection to the selected network after an adjusted delay.

Due to the lack of the global view, most of existing work failed to be an optimal scheme. The emergence of the Software-Defined Network (SDN) [2] technique provides a chance to break this limitation. The SDN controller has an abstracted centralized control of network devices. We make use of this feature of SDN, and propose a novel QoS based Vertical Handoff (QoS-VH) scheme. From the standpoint of mobiles, the QoS-VH scheme chooses *the maximum effective data receiving rate* as the QoS metric. When mobiles need vertical handoffs, they will calculate the QoS values of their available networks. These calculated QoS values are contained in some request frames, and sent to the corresponding networks. We formulate the network selection process as an 0-1 integer programming problem, with the objective of maximize the overall QoS, as well as avoid the network congestion. After the network selection process is finished, mobiles have to wait for a stability period [3], then calculate the QoS values of their current networks and selected networks again. Only if the selected networks are consistently more appropriate than the current networks, mobiles transfer their inter-network connections to the selected networks.

The rest of this paper is organized as follows. The system description and problem formulation are given in section II. Section III and section IV present the proposed scheme for network selection and handoff timing respectively. Section V is the performance evaluation. Section VI concludes this paper.

II. System Description and Problem Formulation

A. System Description

In this paper, we study the vertical handoff problem in the heterogeneous wireless networks with the support of the Software-Defined Network (SDN) technique [2]. Specifically, we consider a heterogeneous wireless network which consists of k network devices (access points or base stations). Let A

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be the set of network devices, where $A = \{a_1, a_2, \cdots, a_k\}$. These network devices support different wireless techniques. In the coverage area of k network devices, there are h mobiles. Let M be the set of mobiles, where $M = \{m_1, m_2, \cdots, m_h\}$. The set A and set M construct an adjacency matrix $C_{h\times k}$, which reflects the relationship between network devices and mobiles. If the mobile m_i ($1\leq i \leq h$) can connect to the network device a_j ($1\leq j \leq k$) directly, the corresponding element c_i^j is 1. Otherwise c_i^j is 0.

Let l_i^j denote the link between m_i and a_j. We assume the bandwidth of l_i^j at time t is $b_i^j(t)$ in hertz. If $c_i^j = 0$, the value of $b_i^j(t)$ is 0. Let $s_i^j(t)$ denote the received signal power of l_i^j at time t in watt. If $c_i^j = 0$, the value of $s_i^j(t)$ is 0. Furthermore, the additive white Gaussion noise (AWGN) with power $n_i^j(t)$ at time t is assumed. If $c_i^j = 0$, $n_i^j(t) \rightarrow +\infty$. Thus, the maximum data transmission rate of the mobile-network pair $\langle m_i, a_j\rangle$ at time t can be calculated by the Shannon equation as follows,

$$T_i^j(t) = b_i^j(t)\log\left(1+\frac{s_i^j(t)}{n_i^j(t)}\right). \tag{1}$$

If there is no noise interference, the transmitted data will be received perfectly correct. That is to say, the data receiving rate equals to the data transmission rate. However, there are various interferences in real channels. These interferences incur the bit errors. Let $e_i^j(t)$ denote the bit error rate of l_i^j at time t. If l_i^j adopts the w-ary code method [7], $e_i^j(t)$ is calculated by the following equation [8],

$$e_i^j(t) = \mathbb{E}(s_i^j(t), n_i^j(t)) = \frac{2(w-1)}{w}\mathbb{Q}\left(\sqrt{\frac{3s_i^j(t)}{(w^2-1)n_i^j(t)}}\right),$$
$$\text{where } \mathbb{Q}(x) = \int_x^\infty \frac{1}{\sqrt{2\pi}}e^{-\frac{x^2}{2}}dy. \tag{2}$$

Definition 2.1 (*The maximum effective data receiving rate*). The maximum effective data receiving rate is the maximum rate that the transmitted data can be received correctly.

From the standpoint of mobiles, only the correctly received data is meaningful. Thus, we choose *the maximum effective data receiving rate* as the Quality of Service (QoS) metric. That is, mobiles evaluate their available networks on the maximum effective data receiving rates. Let $q_i^j(t)$ denote the maximum effective data receiving rate of l_i^j at time t, which also means the QoS value of l_i^j. The value of $q_i^j(t)$ is calculated by the following equation,

$$q_i^j(t) = T_i^j(t)\left(1-e_i^j(t)\right). \tag{3}$$

Traditionally, each network device contains both a control plane and a data plane. The control plane decides whether a traffic is forwarded or not, and to where the traffic should be forwarded. The data plane forwards the traffic according to the decision made by the control plane. In the SDN architecture (Fig.1), an SDN controller separates control planes from data planes of network devices, and provides a centralized control of these network devices. The SDN controller communicates with network devices via OpenFlow, and has a global view of the network devices. This feature of SDN gives us an opportunity to design an optimal vertical handoff scheme.

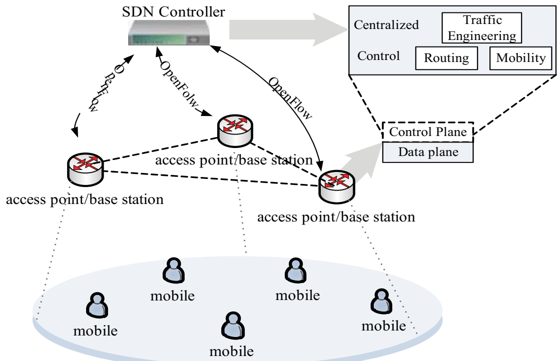


Fig. 1. Network architecture of SDN.

B. Problem Formulation

For mobile m_i, the number of available networks is $\sum_{j=1}^{k} c_i^j$. If the performance of current network degrades to a certain degree, m_i needs vertical handoff. It has to select a network from $\sum_{j=1}^{k} c_i^j - 1$ networks, and transfers its inter-network connection to the selected network. We define the vertical handoff request vector as follows:

Definition 2.2 (*The vertical handoff request vector of a mobile*). The vertical handoff request vector of mobile m_i is $\vec{R}_i$, where $\vec{R}_i = \{r_i^1, r_i^2, \cdots, r_i^k\}$. If $c_i^j = 1$, the corresponding element $r_i^j = q_i^j(t)$. If $c_i^j = 0$, r_i^j could be any negative number, and we simply set it to -1 in this paper.

The SDN controller selects a network for m_i, based on its vertical handoff request vector $\vec{R}_i$. Assume that, the network selection result of m_i is $\vec{F}_i = \{f_i^1, f_i^2, \cdots, f_i^k\}$. The value of element f_i^j can only be 1 or 0. f_i^j equals to 1 means the selected network of m_i is a_j. Otherwise, f_i^j is 0. Therefore, the QoS value of the selected network for m_i is $\sum_{j=1}^{k}\left(f_i^j\cdot r_i^j\right)$. Given a set of mobile-network pairs $\langle M, A\rangle$, the SDN controller selects networks with the purpose of maximizing the sum of QoS values that mobiles can obtain (overall QoS), as well as avoiding network congestion. According to the above definitions and discussions, we theoretically formulate the network selection as follows:

$$\max_{F} \quad \sum_{i=1}^{h}\sum_{j=1}^{k}\left(f_i^j\cdot r_i^j\right). \tag{4}$$

$$\text{subject to}: \quad f_i^j = 0 \quad or \quad f_i^j = 1, \tag{5}$$

$$\sum_{j=1}^{k} f_i^j \leq 1 \quad (1\leq i\leq h), \tag{6}$$

$$\sum_{i=1}^{h}(f_i^j\cdot r_i^j) \leq T_j \quad (1\leq j\leq k). \tag{7}$$

Our objective is to maximize the overall QoS (Eq. (4)). The value of f_i^j indicates whether a_j is the selected network of mobile m_i or not. If a_j is the selected network of m_i, f_i^j equals to 1. Otherwise, f_i^j equals to 0 (Eq. (5)). For each mobile, it has at most one selected network (Eq. (6)). Furthermore, since the resources of networks are limited, the requested resources should not exceed the capability of networks. Let T_j

denote the available bandwidth of a_j. In order to avoid network congestion, the requested data transmission rate should be smaller than T_j (Eq. (7)). After the network selection is formulated as an 0-1 integer programming problem, it can easily be solved by using some tools like matlab or lingo.

III. Network Selection Strategy

Based on the previous problem formulation, we propose a network selection strategy for vertical handoff. The Software-Defined Network (SDN) controller selects networks for mobiles in three phases: initialization, request matrix construction and network selection.

A. Strategy Details

Phase 1. Initialization

In each time slot, mobiles evaluate their current networks and determine whether to initiate vertical handoffs or not. If a mobile needs vertical handoff, it will send request frames to its available networks. The values of request frames are the QoS values of corresponding networks. If a mobile does not need vertical handoff, it also sends request frames to its available networks. In this case, the request frames are just like Hello messages, and their values are -1.

Phase 2. Request matrix construction

According to the received information of networks, the SDN controller constructs a request matrix $R = \left(\vec{R_1}, \vec{R_2}, \cdots, \vec{R_h}\right)^{\mathrm{T}}$. At first, the request matrix R is incomplete. There are some elements, whose value are unknown. These elements are defined as the unassigned elements.

Definition 3.1 (*unassigned element*). The unassigned element is the element of request matrix, whose value is unknown due to the corresponding network and mobile can not communicate directly.

Since the SDN controller has the global view, it can complete the request matrix R after some calculations. The calculation rules of unassigned elements are as follows: (1) if the remaining elements of the corresponding vertical handoff request vector are -1, the unassigned elements are -1; (2) if the remaining elements of the corresponding vertical handoff request vector are not -1, the unassigned elements are 0.

Phase 3. Network selection

After constructing the request matrix R, the SDN controller selects networks for mobiles. The network selection is formulated as an 0-1 programming problem (Eq. (4)). The SDN controller calculates the network selection results by solving this 0-1 programming problem. The network selection results are presented as a $h \times k$ matrix F. According to F, the SDN controller sends out feedback frames. If the element f_i^j is 1, that means a_j is the selected network of mobile m_i. Therefore, the SDN controller sends an OpenFlow message to network a_j. Then, a_j sends a feedback frame to mobile m_i to notify this result.

B. An Example

In this subsection, we will use an example to explain the network selection strategy in detail. Specifically, we consider a scenario shown in Fig. 2. There are three network access points (i.e, a_1, a_2, a_3). These access points support different wireless techniques. An SDN controller centralized controls

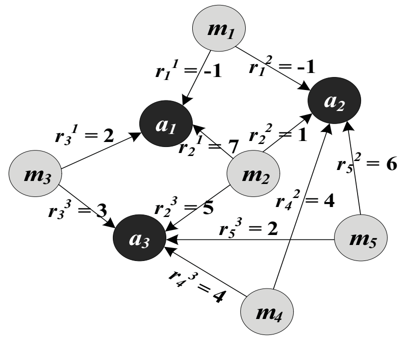


Fig. 2. An example of the proposed network selection strategy.

these access points. In the coverage area of three access points, there are five mobiles (i.e, m_1, m_2, m_3, m_4, m_5). Supposing in a time slot, m_1 does not need vertical handoff. Meanwhile, other four mobiles (m_2, m_3, m_4 and m_5) need vertical handoffs.

Phase 1. Initialization

Since m_1 dose not need vertical handoff, it will send request frames r_1^1 and r_1^2 to the available networks a_1 and a_2 respectively. The values of r_1^1 and r_1^2 are -1. Meanwhile, other four mobiles m_2, m_3, m_4 and m_5 need vertical handoffs, they also have to send out request frames. Take m_2 for instance, a_1, a_2 and a_3 are available to m_2. We do not need to consider which network m_2 is connecting to. As long as m_2 needs vertical handoff, m_2 will send request frames to the three available networks. Let r_2^1 denote the request frame send from m_2 to a_1. The value of r_2^1 equals to the QoS value of link l_2^1. In our example r_2^1 is 7, which means if m_2 chooses a_1 as its selected network, the maximum effective data receiving rate that m_2 can get is 7 Mbps. Similarly, other mobiles send vertical handoff requests to their available networks.

Phase 2. Request matrix construction

After receiving the request frames, the SDN controller constructs a request matrix R shown in Eq.(8). At first, there are four unassigned elements (i.e., r_1^3, r_3^2, r_4^1 and r_5^1) in the matrix R. Take the element r_1^3 for instance, since the network a_3 is unavailable to mobile m_1, m_1 will not send request frame to a_3. Therefore, the SDN controller can not determine the value of r_1^3 in the beginning.

$$R = \begin{array}{c} \\ \boldsymbol{m_1} \\ \boldsymbol{m_2} \\ \boldsymbol{m_3} \\ \boldsymbol{m_4} \\ \boldsymbol{m_5} \end{array} \begin{array}{c} \begin{array}{ccc} \boldsymbol{a_1} & \boldsymbol{a_2} & \boldsymbol{a_3} \end{array} \\ \begin{pmatrix} -1 & -1 & r_1^3 \\ 7 & 1 & 5 \\ 2 & r_3^2 & 3 \\ r_4^1 & 4 & 4 \\ r_5^1 & 6 & 2 \end{pmatrix} \end{array}. \tag{8}$$

Based on this primary request matrix, the SDN controller calculates the value of unassigned elements. Still take the element r_1^3 for example, since other elements of the first row vector are -1, the value of r_1^3 should be -1. Similarly, since other elements of the third row vector are not -1, the value of r_3^2 should be 0. After some calculations, the SDN controller completes the request matrix R as follows,

$$R = \begin{array}{c} \\ \boldsymbol{m_1} \\ \boldsymbol{m_2} \\ \boldsymbol{m_3} \\ \boldsymbol{m_4} \\ \boldsymbol{m_5} \end{array} \begin{array}{c} \begin{array}{ccc} \boldsymbol{a_1} & \boldsymbol{a_2} & \boldsymbol{a_3} \end{array} \\ \begin{pmatrix} -1 & -1 & \mathbf{-1} \\ 7 & 1 & 5 \\ 2 & \mathbf{0} & 3 \\ \mathbf{0} & 4 & 4 \\ \mathbf{0} & 6 & 2 \end{pmatrix} \end{array}. \tag{9}$$

Phase 3. Network selection

Based on the request matrix R, the SDN controller formulates the network selection as an 0-1 programming problem (Eq.(4)). The solution of this 0-1 programming problem is the network selection result, which is presented as a matrix F. Assuming that, the maximum data transmission rates of a_1, a_2 and a_3 are 10 Mbps, 8 Mbps and 6 Mbps respectively. After some calculations, the SDN controller gets a 5×3 matrix F as follows,

$$F = \begin{array}{c} \\ \boldsymbol{m_1} \\ \boldsymbol{m_2} \\ \boldsymbol{m_3} \\ \boldsymbol{m_4} \\ \boldsymbol{m_5} \end{array} \begin{array}{c} \begin{array}{ccc} \boldsymbol{a_1} & \boldsymbol{a_2} & \boldsymbol{a_3} \end{array} \\ \begin{pmatrix} f_1^1 & f_1^2 & f_1^3 \\ f_2^1 & f_2^2 & f_2^3 \\ f_3^1 & f_3^2 & f_3^3 \\ f_4^1 & f_4^2 & f_4^3 \\ f_5^1 & f_5^2 & f_5^3 \end{pmatrix} \end{array} = \begin{array}{c} \\ \boldsymbol{m_1} \\ \boldsymbol{m_2} \\ \boldsymbol{m_3} \\ \boldsymbol{m_4} \\ \boldsymbol{m_5} \end{array} \begin{array}{c} \begin{array}{ccc} \boldsymbol{a_1} & \boldsymbol{a_2} & \boldsymbol{a_3} \end{array} \\ \begin{pmatrix} 0 & 0 & 0 \\ \mathbf{1} & 0 & 0 \\ \mathbf{1} & 0 & 0 \\ 0 & 0 & \mathbf{1} \\ 0 & \mathbf{1} & 0 \end{pmatrix} \end{array}. \tag{10}$$

The value of f_2^1 is 1 means, the selected network of mobile m_2 is a_1. That is to say, m_2 should transfer its inter-network connection from the current network to a_1. Therefore, a_1 should send a feedback frame to m_2 to notify this selection result. Similarly, a_1 sends a feedback frame to m_3. a_2 sends a feedback frame to m_5, and a_3 sends a feedback frame to m_4.

IV. Handoff Timing Strategy

Since the mobiles are always moving around, mobiles should not handoff to their selected networks immediately. In our proposed scheme, mobiles will wait for a stability period τ after their selected networks are determined. Only if the selected networks are **consistently** more **appropriate** than their current networks, mobiles handoff to their selected networks. Before we start to introduce our proposed handoff timing strategy, there are two things needed to be explained specially. The first thing is about the meaning of *appropriate*. In this paper, we use "appropriate" instead of "better". The reason is even the selected network is better than the current network, if the current network can satisfy the demand of a mobile, this mobile should not perform the vertical handoff. The second thing is about the length of a *stability period* τ. Some related work has been conducted in calculating the value of τ [3]. However, the calculation method of τ is not the interest of this paper. In our research, we just simply set τ to a random value.

For a mobile m, we assume its current network and selected network are a_1 and a_2 respectively (Fig.3). Following the previous definitions, the Quality of Service (QoS) values of a_1 and a_2 at time t were $q_1^1(t)$ and $q_1^2(t)$ respectively. After waiting for a stability period τ, the QoS values of a_1 and a_2

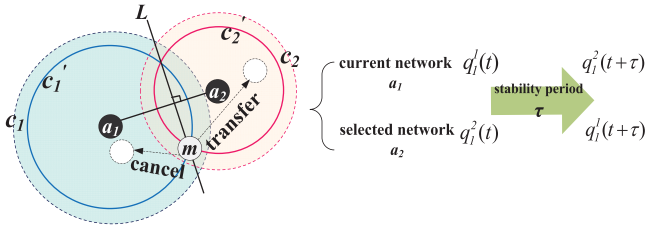


Fig. 3. An example of the proposed handoff timing strategy.

become $q_1^1(t+\tau)$ and $q_1^2(t+\tau)$ respectively. Based on these QoS values, m can determine whether to transfer its inter-network connection from a_1 to a_2 or not. As the example shown in Fig.3, the coverage area of a_1 is the circular region insides c_1. The closer to a_1, the better QoS that m can get from a_1. c_1 and c_1' are concentric circles. If m moves along c_1', the QoS value of a_1 will not change. Similarly, the coverage area of a_2 is the circular region insides c_2. If m moves along c_2', the QoS value of a_2 will not change. There is a line L, which is perpendicular to the line between a_1 and a_2. We consider that,

- if m moves to the left of L, which means m has the tendency of close to a_1. Since mobile was moving back to its current network during the stability period, it does not need vertical handoff anymore, and the network selection result is canceled;
- if m moves to the right of L, which means m has the tendency of close to a_2. Since mobile was moving away from its current network during the stability period, it has to transfer the inter-network connection to the selected network at once.

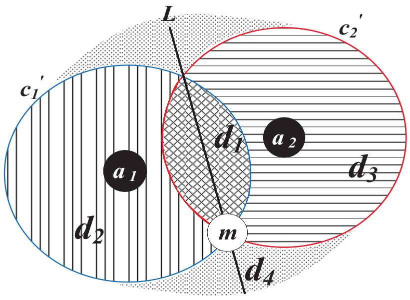
Since the movement trend of a mobile is important for the vertical handoff, some related work tried to predict the movement trend of a mobile. The existing work is based on location information [9], context [10] or historical record [11] and so on. Each of them requires a lot of storage space. In this paper, we predict the movement trend just based on QoS values of the current network and selected network. Discussions are provided for the following nine cases.

1) $q_1^1(t) < q_1^1(t+\tau)$ and $q_1^2(t) < q_1^2(t+\tau)$. Since the QoS value of a_1 increases, m must be inside c_1'. For the same reason, m is also inside c_2'. That is to say, after a stability period, m locates at the domain d_1 shown in Fig.4 (a). The line L passing through d_1, so we can not determine the movement trend of m. As a result, m should wait for another stability period, and then analyze the situation again.

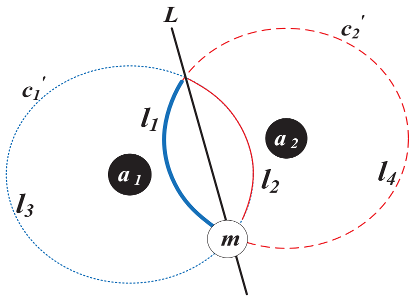
2) $q_1^1(t) < q_1^1(t+\tau)$ and $q_1^2(t) = q_1^2(t+\tau)$. Since the QoS value of a_2 has no change, m must be locating at c_2'. Furthermore, m is inside c_1'. That is to say, after a stability period, m locates at the line segment l_1 shown in Fig.4 (b). l_1 is on the left of L, which means m moves back. As a result, m does not need vertical handoff anymore.

3) $q_1^1(t) < q_1^1(t+\tau)$ and $q_1^2(t) > q_1^2(t+\tau)$. Since the QoS value of a_2 decreases, m must be outside c_2'. Furthermore, m is inside c_1'. That is to say, after a stability period, m locates at the domain d_2 shown in Fig.4 (a). d_2 is on the left of L, which means m moves back. As a result, m does not need vertical handoff anymore.

4) $q_1^1(t) = q_1^1(t+\tau)$ and $q_1^2(t) < q_1^2(t+\tau)$. Since the



(a) a mobile moves into a domain



(b) a mobile moves on a line

Fig. 4. The movement directions of a mobile.

QoS value of a_1 has no change, m must be locating at c_1'. Furthermore, m is inside c_2'. That is to say, after a stability period, m locates at the line segment l_2 shown in Fig.4 (b). l_2 is on the right of L, which means m moves away. As a result, m transfers to the selected network a_2 at once.

5) $q_1^1(t) = q_1^1(t+\tau)$ and $q_1^2(t) = q_1^2(t+\tau)$. Since the QoS values of a_1 and a_2 have no change, m still locates at the original point after a stability period. We can not determine the movement trend of m. As a result, m should wait for another stability period, and then analyze the situation again.

6) $q_1^1(t) = q_1^1(t+\tau)$ and $q_1^2(t) > q_1^2(t+\tau)$. Since the QoS value of a_2 decreases, m must be outside c_2'. Furthermore, m locates at c_1'. That is to say, after a stability period, m locates at the line segment l_3 shown in Fig.4 (b). l_3 is on the left of L, so m does not need vertical handoff anymore.

7) $q_1^1(t) > q_1^1(t+\tau)$ and $q_1^2(t) < q_1^2(t+\tau)$. Since the QoS value of a_1 decreases, m must be outside c_1'. Furthermore, the QoS value of a_2 increases, m must be inside c_2'. That is to say, after a stability period, m locates at the domain d_3 shown in Fig.4 (a). d_3 is on the right of L, so m transfers to a_2 at once.

8) $q_1^1(t) > q_1^1(t+\tau)$ and $q_1^2(t) = q_1^2(t+\tau)$. Since the QoS value of a_2 has no change, m must be locating at c_2'. Furthermore, the QoS value of a_1 decreases, m is outside c_1'. That is to say, after a stability period, m locates at the line segment l_4 shown in Fig.4 (b). l_4 is on the right of L, so m transfers to a_2 at once.

9) $q_1^1(t) > q_1^1(t+\tau)$ and $q_1^2(t) > q_1^2(t+\tau)$. Since the QoS value of a_2 decreases, m must be outside c_2'. Furthermore, m is outside c_1'. That is to say, after a stability period, m locates at the domain d_4 shown in Fig.4 (a). The line L passing through d_4, so we can not determine the movement trend of m. As a result, m should wait for another stability period, and then analyze the situation again.

In order to predict the movement trend of a mobile, system only need to store the QoS values of its current network and selected network. From the above analysis we can see, only if the mobile is certain to move away from its current network, vertical handoff will be implemented.

V. Performance Evaluation

In this section, we provide the performance evaluation of our proposed QoS based Vertical Handoff (QoS-VH) scheme. We compare the QoS-VH scheme with three typical existing schemes: the Always Best Connected (ABC) scheme [12], Smooth Adaptive Soft Handover Algorithm (SASHA) [5] and Enhanced Group Handover Scheme (EGHS) [6]. The ABC scheme is the basic vertical handoff scheme without optimization. In ABC, once a mobile needs handoff, it will transfer its inter-network connection to the best performance network immediately.

Over a 500m $\times$ 500m rectangular flat space, mobiles move around randomly. We compare the number of handoffs, and the sum of QoS values that mobiles can obtain (overall QoS) in four vertical handoff schemes. Simulation experiments are repeated one hundred times and the simulation results are presented with 95% confidence interval. Some important experimental parameters are presented in Table I.

TABLE I. Experimental Parameters

Parameter	Value
Bit error rate	Less than 0.1
Simulation area	500*500 m^2
Simulation times	100 times
Stability period	Less than 1 second
Code method	Binary unipolar code
Noise interface	Less than 100 dBm

A. Number of Vertical Handoffs

There are three access points in the area, their bandwidths are 54Mbps (Wi-Fi), 100Mbps (LTE) and 324Mbps (WiMAX) respectively. We assume that if the available bandwidth is less than the required bandwidth, a mobile will initialize handoff. For each mobile, the value of required bandwidth is randomly selected between 1Mbps and 2Mbps, which corresponds to the video conference requirement. We increase the number of mobiles from 10 to 100, and count the number of handoffs. Simulation results are shown in Fig.5.

Fig.5 shows that, the number of vertical handoffs increases if the number of mobiles increases. In ABC, if there are 100 mobiles in the area, nearly 65% mobiles need handoffs. Meanwhile, there are less than 42% mobiles need handoffs in our proposed QoS-VH scheme. From Fig.5 we can see that, our proposed scheme has the least number of handoffs. Furthermore, as the number of mobiles increases, the QoS-VH scheme has the slowest increasing speed of the number of vertical handoffs.

B. Overall Quality of Service

In this subsection, we compare the overall QoS in four vertical handoff schemes. We fix the number of access points,

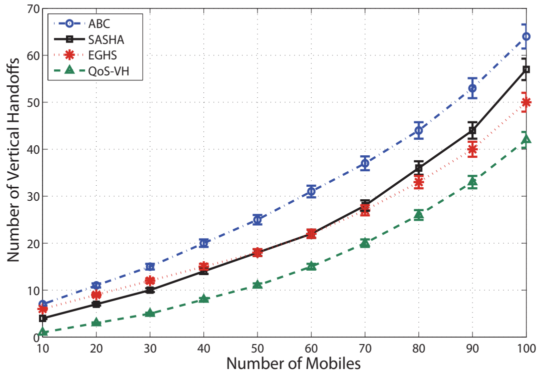


Fig. 5. The number of vertical handoffs vs. the number of mobiles.

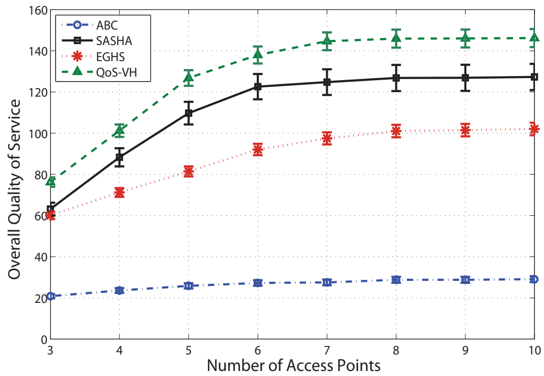


Fig. 7. The overall quality of service vs. the number of access points.

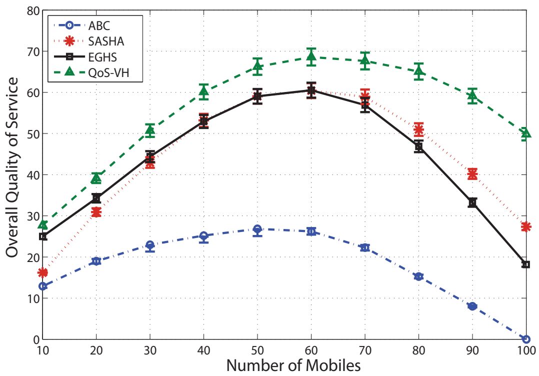


Fig. 6. The overall quality of service vs. the number of mobiles.

and study the relationship between the overall QoS and mobiles. Considering a network which has three access points. We increase the number of mobiles from 10 to 100, and calculate the overall QoS that mobiles can obtain. Simulation results are shown in Fig.6. From Fig.6 we can see that, as the number of mobiles increases, the overall QoS will increase at first. After the number of mobiles increases to about 60, the overall QoS will decrease. This phenomenon is due to the network congestion. The simulation results in Fig.6 also illustrate that, our proposed QoS-VH scheme has the maximum overall QoS.

We also compare the overall QoS of four vertical handoff schemes, when the number of access points changes. We fix the number of mobiles, and study the relationship between the overall QoS and access points. Considering a network which has 50 mobiles. We increase the number of access points from 3 to 10, and calculate the overall QoS that mobiles can obtain. Simulation results in Fig.7 shows that, as the number of access points increases, the overall QoS will increase at first, then remain stable. For the same number of access points, our proposed QoS-VH scheme has the biggest overall QoS.

VI. Conclusion

In this paper, we propose a Quality of Service based Vertical Handoff (QoS-VH) scheme with the support of the Software-Defined Network (SDN) technique. The proposed scheme ensures that, a mobile will transfer to the most appropriate network at the most appropriate time. We compared our proposed scheme with the typical existing schemes: ABC [12], SASHA [5] and EGHS [6]. Simulation results demonstrated the proposed scheme reduces the number of vertical handoffs, and maximizes the overall QoS significantly.

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