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The QoS-Ensured Vertical Handoff Decision in Heterogeneous Wireless Networks*

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The multi-criteria vertical handoff algorithm plays an important role in heterogeneous wireless networks. There are two drawbacks in the available multi-criteria vertical handoff algorithms. The conventional algorithms do not give the feasible method to determine attribute weight values, and do not also consider the dependency relationship among the decision attributes, which are not mutually independent. These factors make it challenge to select the QoS-ensured network for vertical handoff in heterogeneous wireless networks. This paper proposes a method to determine weight values of each attribute according to the importance degree by using analytic hierarchy process. In order to eliminate the interaction among various criteria, we also propose a novel principal component extraction method based on principal component analysis, which can rapidly choose the QoS-ensured network with lower compute cost by only using less of the synthetic components. Extensive experiment illustrates the performance of the proposed algorithm compared with previous schemes, and the results show that the proposed vertical handoff decision algorithm can effectively eliminate the interaction among the original decision attributes, and extract the principal components (Only the first two principal components are able to seize 98% criteria information of the original decision information.). This algorithm can accurately select the QoS-ensured network with fewer principal components.

Keywords: heterogeneous wireless networks, vertical handoff, multi-criteria decision, attribute weight determination, principal component extraction

1. INTRODUCTION

The varying wireless technologies are driving wireless networks to become heterogeneous and integrate ones. The next generation wireless networks (NGWN) combine various wireless networks (Vehicular Ad-hoc NETwork (VANET), Wireless Local Area Networks (WLANs), Universal Mobile Telecommunications System (UMTS), et al.) and provide a ubiquitous environment of wireless access for mobile terminals (MT) equipped with multiple network interfaces [1]. Due to the promising applications of heterogeneous wireless networks in many important scenarios (like joint military networks, vehicle networks, joint disaster recovery networks), the consideration of QoS-ensured vertical handoff decision in such networks is of important for ensuring the efficiency of network operation. It is significant for cross-network applications to transfer across multiple wireless network interfaces easily and smoothly.

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The heterogeneous wireless interconnection can provide ubiquitous coverage, improve the systems resource utilization and satisfy user requirements. The seamless and high efficient handoff among different access technologies (vertical handoff) is essential and remains a challenging problem in heterogeneous wireless networks. The heterogeneous co-existence of access technologies with different characteristics results in handoff asymmetry that differs from the traditional intra-network handoff (horizontal handoff) problem. In heterogeneous wireless networks, the requirements for vertical handoffs can be initiated for better QoS rather than only connectivity reasons [2]. The process of vertical handoff consists of three steps, namely system discovery, handoff decision and handoff execution. During the system discovery, a mobile terminal equipped with multiple interfaces has to determine the networks can be used and the available services in each network. During the handoff decision phase, the mobile terminal determines which the optimal access network is. During the handoff execution phase, connections are needed to be re-routed from the current network to the selected network in a seamless manner [3].

The optimal network selection is a key issue in the vertical handoff decision phase. This multi-criteria nature of the algorithm allows simultaneous consideration of several significant aspects of the vertical handoff process in order to enhance the system performance in accordance with the defined heterogeneous network goals. The network selection decision may depend on various groups of parameters such as network related, terminal related, user related and service related [4, 5]. The single criteria vertical handoff algorithm merely reflects the specified network characteristic, which is not sufficient to characterize the network QoS. The network QoS is integration of all network characteristics. Therefore, the multi-critical vertical handoff algorithm is essential in heterogeneous wireless networks, which can provide better performance than a single criteria vertical handoff algorithm due to the additional of evaluation parameters and the great potential for achieving the desired balance among different system characteristics [6].

There are two drawbacks in available multi-criteria vertical handoff algorithm. (1) To the knowledge of us, there is no multi-criteria decision algorithm which provides the feasible method to determine reasonable attribute weight values. This is why the available works are difficult to quantitatively evaluate the network QoS. (2) The dependence among attributes is not considered in available studies. In this case, some properties may be considered repeatedly. These factors make it very difficult to select QoS-ensured network. Therefore, these two problems are the main bottlenecks to select the QoS-ensured access network. It is essential and challenge work to solve these two problems. This paper focuses on the multi-criteria vertical handoff algorithm in heterogeneous wireless networks. The main contributions of this paper are as follows.

(1) By taking network related, terminal related, user related and service related attributes into account, we propose a method to determine attribute weight values based on the analytic hierarchy process, which can quantitatively assess the QoS of each candidate network according to the importance degree of each attribute.
(2) The relationship among the various attributes is analyzed, and find these attributes are not independent mutually which leads to inaccurate network selection. We propose a principal component extraction method to eliminate the interaction among the original decision attributes.

(3) Extensive experiment studies are also conducted to illustrate the performance improvement of our proposal compared with previous schemes.

The remainder of the paper is organized as follows. Related work is summarized in section 2. The method to determine attribute weight values is proposed in section 3. The method to eliminate the interaction among the various attributes and the network selection algorithm based on principal component extraction method are presented in section 4. Section 5 gives experimental verification and analysis. Conclusions are presented in section 6.

2. RELATED WORKS

In this section, we present an overview of the related works on multi-attribute-based network selection for vertical handoff in heterogeneous wireless networks.

The heterogeneous wireless networks have attracted a lot of attentions. There are various standardization working group towards this vision, such as the 3rd Generation Partnership Project (3GPP) [7], 3GPP2 [8], and the IEEE 802.21 Media Independent Handoff (MIH) working group [9]. The goal of B3G/4G wireless networks is to integrate various heterogeneous wireless access networks over an IP (Internet Protocol) backbone. 3GPP and 3GPP2 have standardized the interconnection requirements between 3G wireless cellular systems and WLANs to provide handoff support between both systems.

The optimal network selection is key problem for vertical handoff in heterogeneous wireless networks. The approach, based on the traditional strategy of using RSS (received signal strength), is not suitable for the integration scenarios of heterogeneous wireless networks, because of the differences among various wireless networks [10]. With the development of the heterogeneous wireless network integration, various multi-attribute-based selection algorithms for vertical handoff have been proposed in the recent literature. (1) Network assessment methods based on cost function [11-13]; (2) Handoff decision based on multiple attributes [14-16]; (3) Network selection method based on computational intelligence techniques [17-21]; (4) Network selection method based on the context information of the mobile terminal and networks [23, 24].

In [11], Nasser *et al.* propose a vertical handoff decision cost function with multi-attributes that provides handoff decision for the heterogeneous wireless networks. In [12], a utility based strategy for network selection is proposed. Several utility cost functions are evaluated based on the economic concepts of consumer surplus and risk. However, they do not provide some methods to determine the coefficients (weights) of parameters in the cost function, and do not consider the interaction among various properties.

An integrated network selection algorithm is presented in [14] with multiple network parameters, which uses two multiple attribute decision making methods, analytical hierarchy process (AHP) and Grey relational analysis (GRA). The common multi-critical vertical handoff algorithm, such as Multiplicative Exponent Weighting (MEW), Simple Additive Weighting (SAW), and Technique for Order Preference by Similarity to Ideal Solution (TOPOSIS) [15], allow a variety of attributes to be included for vertical handoff decision. Simulation results show that MEW, SAW and TOPSIS provide similar performance to all four traffic classes (conversational, streaming, interactive and background).

GRA provides a slightly higher bandwidth and lower delay for interactive and background traffic classes. However, these multiple attribute decision making methods cannot determine the reasonable weight values for each property and the interaction among the various properties is not considered.

In [16], a framework is proposed to compare different vertical handoff algorithms. The framework includes a path loss channel model between mobile terminal and access point, and a Markov chain that models user movement among different access networks. In [17], the vertical handoff decision is formulated as a fuzzy multiple attribute decision making (MADM) problem. Fuzzy logic is used to represent the imprecise information of the network attribute and the user preferences. The fuzzy decision method, consisting of two steps (converts the fuzzy data into a real number and uses classical MADM methods), determines the rank of the candidate networks [18]. In [19], an Artificial Neural Network (ANN) is used to control and manage handoffs across heterogeneous wireless networks. A fuzzy logic inference system has been proposed to process a multi-criteria vertical handoff decision metrics for integration and interoperation of heterogeneous networks [13]. In [10], two vertical handoff decision-making schemes have been proposed based on fuzzy logic and neural networks. In [20], a mobility management was proposed in a packet-oriented multi segment using mobile IP and fuzzy logic concept. Because these decision algorithms are too complex, it is very difference to employ in the practice heterogeneous wireless networks as the limited terminal capacity.

The vertical handoff decision algorithm with the knowledge of context information of the mobile terminal and networks can make better decisions [21]. In [22], the authors present a framework with an analytical context categorization and a handoff decision algorithm. The application scope of these algorithms is limited, since they cannot be used in the scenes without the context information of mobile terminal and networks.

3. WEIGHT DETERMINED METHOD BASED ON ANALYTIC HIERARCHY PROCESS

In this section, by taking network related, terminal related, user related and service related attributes into account, we propose a multi-attribute network selection model. Based on the analytic hierarchy process, we propose a scheme to determine attribute weight values, which can quantitatively assess the QoS of each candidate network.

3.1 The Accessing Network Selected Model

The Always Best Connected (ABC) refers to the mobile terminals equipped with multiple network interfaces will always select the most appropriate one as the access network. From a different point of view, ABC has a different meaning. From the network operator view, ABC is to reduce network resource consumption as much as possible and at the same time to ensure minimum QoS requirements of users. From the user view, ABC is to minimize user charges, in the case of maximize QoS for users. The ABC concept suggests the user preferences as part of the vertical handoff decision metrics. The paper takes network parameters, user preferences, terminal performance parameters and application requirements into account, and proposes a method to choose the best network connection at anytime.

We first establish a multi-attribute decision matrix, and propose a network selection model. There are n available networks in the candidate network set $A = \{A_1, A_2, \ldots, A_n\}$. There are m attributes in the decision parameter set $G = \{G_1, G_2, \ldots, G_m\}$. Then the multi-attribute decision matrix Y is formed.

$$Y = (y_{ij})_{n\times m} = \begin{bmatrix} y_{11} & y_{12} & y_{13} & \cdots & y_{1m} \\ y_{21} & y_{22} & y_{23} & \cdots & y_{2m} \\ y_{31} & y_{32} & y_{33} & \cdots & y_{3m} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ y_{n1} & y_{n2} & y_{n3} & \cdots & y_{nm} \end{bmatrix}$$

Here, y_{ij} is the sample value of G_j attached to candidate network A_i. The mobile terminal with running service s is covered by the multiple candidate network signals. User mobility, service requirement and network environmental changes may result in the changes of network QoS, which will trigger the vertical handoff. Denote QoS of the network A_i by Q_i. The optimization target of network selection is as follow.

$$A_{opt} = \arg\max_{1\le i\le n}(Q_i)$$

Q_i is contributed by various network parameters, including user preferences, terminal performance parameters, application requirements *etc*. The importance of each parameter is different, thus the contribution of each parameter to candidate network QoS is different.

3.2 Weight Determined Method

The QoS requirements of the different types of service are expressed as the parameter selection and the importance degree. Therefore, for different applications, various attributes should be assigned different weights to evaluate the network QoS level. We define the accuracy of the vertical handoff as the probability that the terminal accesses optimal target network in the vertical handoff process, which is very important to determine the weight values of the attributes in the vertical handoff decision algorithm. Whether the weight value of each attribute is reasonable leads directly to the accuracy of the target network selection.

There are the network related, terminal related, user related and service related attributes in the network selection process. The network related parameters are mainly defined as bandwidth, latency, RSS, SIR (Signal to Inference Ratio), cost, security *etc*. The terminal related parameters are mobile velocity, battery power, location information *etc*. User related deals with user profile and preferences, service capacities *etc*. Service related is the service requirements. Thus, these attributes form a hierarchical tree structure of which the leaf node represents each decision attribute.

It is a significant work to determine the important degree of each attribute contributed to the QoS, which is represents by the weight value of corresponding attribute. Thus, our contribution is to determine reasonably the weight value of each parameter. Since AHP has been demonstrated to be effective multi-attribute decision making method [23, 24], and can convert a complex problem into easily solved sub-problems, therefore, AHP is also suitable for multi-attribute decision vertical handoff in heterogeneous wireless networks. To satisfy the QoS requirements of the current services and users, this paper selects AHP to determine attribute weight values. We divide the decision factors into the different levels using AHP, establish hierarchy diagram to represent the ladder structure of the different levels and the affiliation between adjacent levels. Then, the weight that the each attribute contributes to the target QoS is determined from bottom to up. The process to determine the weight values is as follow.

(1) The attribute assignment hierarchical tree

The attribute assignment hierarchical tree is established according to the classification of metrics and the master-slave relationship of attributes. Each leaf node represents an attribute in this tree. The value of each leaf node is the measure of one attribute. The value of intermediate node represents the contribution of the sub-tree which themselves as the root to the overall objective. Similar attributes are located in the same sub-tree. The attribute assignment hierarchical tree is shown as Fig. 1.

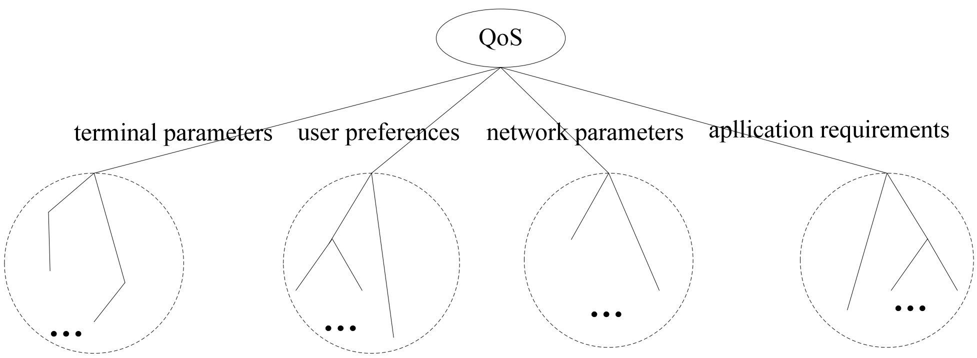

Fig. 1. The attribute assignment hierarchical tree.

(2) The decision matrix structure

The decision matrix is used to determine the important degree of the same level attributes in the attribute assignment hierarchical tree. The decision matrix will be generated in the each attribute layer. The each element value depends on the important degree of each attribute in the decision matrix. We denote the decision matrix as $D = (d_{ij})_{n\times n}$, subject to $d_{ij} > 0$, $d_{ij} = 1/d_{ji}$, $d_{ii} = 1$ for $1 \leq i, j \leq n$.

We can determine the weight of each attribute according to the decision matrix. The method of calculation is as follows. First, we calculate the maximum eigenvalue λ_{max} of the decision matrix D. Then the standardized eigenvector W is calculated with $DW = \lambda_{max}W$. The standardized feature vector $W = (w_1, w_2, \ldots, w_n)$ is treated as n weight values of the attributes.

(3) Combined weight calculation for each layer

After gaining all weight value, the combination weight of each layer is calculated as follows. We assume the $(k-1)$-layer weight vector contribution to the overall goal is $w^{k-1} = (w_1^{k-1}, w_2^{k-1}, \ldots, w_m^{k-1})^T$. If the jth element in the $(k-1)$-level is a attribute, the k-layer elements combined vector $b^k_j = (b^k_{1j}, b^k_{2j}, \ldots, b^k_{nj})^T$. Assume $B^k = (b_1^k, b_2^k, \ldots, b_m^k)^T$, the combined weight of the n elements in the kth level is $w^k = B^k \times w^{k-1}$. By the above procedure, we can accurately establish each attribute weight in the vertical handoff algorithm.

4. THE PRINCIPAL COMPONENT EXTRACTION METHOD IN MULTI-ATTRIBUTE DECISION

The optimal network selection in the vertical handoff is often transferred to be the multi-attribute decision making problem. The network selection may depend on various parameters such as bandwidth, delay, latency, access cost, and transmission power, current battery status of the mobile device and user preferences.

We notice the optimal network selection will be more accurate, if the more attributes are selected. However, the complexity and computation cost will also be higher as the more attributes are selected. We analyze the relationship among the various attributes, and find they are not independent each other. Such as delay, latency, cost, bandwidth, these attributes are interdependent, and some overlap exists among them. This factor seriously affects the accuracy of the network selection. With increasing of the number of attributes, the hierarchical attribute assignment tree will become larger which leads to higher complexity and computation cost.

In this section, we propose a method to eliminate the interaction among the various attributes and make the less integrated independent attributes to replace the original attributes using principal component analysis (PCA).

4.1 The Mathematical Model of Principal Component Analysis

PCA is a common multivariate statistical method, which is able to transform the multi-variable data to less comprehensive data and simplify the high-dimensional variable space with the minimum data loss. The p attributes are concerned for each wireless network, $X_1, X_2, \ldots, X_p$. The original data sample matrix is as follow.

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1p} \\ x_{21} & x_{22} & \cdots & x_{2p} \\ \cdots & \cdots & \cdots & \cdots \\ x_{n1} & x_{n2} & \cdots & x_{np} \end{bmatrix} = (X_1, X_2, \cdots, X_p)$$

Using the linear transformation, we gain p new integrated attributes $F_1, F_2, \ldots, F_p$, which are the linear combinations of $X_1, X_2, \ldots, X_p$.

$$\begin{cases} F_1 = a_{11}X_1 + a_{21}X_2 + \cdots + a_{p1}X_p \\ F_2 = a_{12}X_1 + a_{22}X_2 + \cdots + a_{p2}X_p \\ \qquad \vdots \\ F_p = a_{1p}X_1 + a_{2p}X_2 + \cdots + a_{pp}X_p \end{cases}$$

Abbreviated as

$$F_i = a_{1i}X_1 + a_{2i}X_2 + \ldots + a_{pi}X_p \qquad i = 1, 2, \ldots, p.$$

Here,

$$a_{1i}^2 + a_{2i}^2 + \ldots + a_{pi}^2 = 1 \qquad i = 1, \ldots, p.$$

Each coefficient a_{ij} is determined as the following principles.
(1) F_i, F_j is linearly independent, $1 \le i, j \le p$, $i \ne j$.
(2) F_i ($i = 1, \ldots, p$) is a linear combinations of $X_1, X_2, \ldots, X_p$, whose variance is the maximum except F_j ($j = 1, \ldots, i - 1$). Such as F_1 is a linear combination of $X_1, X_2, \ldots, X_p$, whose variance is the maximum. F_2 is a linear combination of $X_1, X_2, \ldots, X_p$, whose variance is the maximum except F_1. F_p is a linear combinations of $X_1, X_2, \ldots, X_p$, whose variance is the maximum except $F_1, F_2, \ldots, F_{p-1}$.

F_i with satisfying the above conditions is called the ith principal component of $X_1, X_2, \ldots, X_p$, $i = 1, 2, \ldots, p$. $X = (X_1, X_2, \ldots, X_p)^T$ is a p-dimensional random vector. Its covariance matrix is Σ. The eigenvalue of Σ are $\lambda_1 \ge \lambda_2 \ge \ldots \ge \lambda_p \ge 0$, and $a_1, a_2, \ldots, a_p$ are the corresponding unit orthogonal eigenvectors. Then the ith principal component of X is $F_i = a_i^T X$ ($i = 1, 2, \ldots, p$).

4.2 The Principal Component Extraction for QoS

In order to assess the network QoS to the current service s, m decision attributes are selected. Based on the method to determine the weight value of each attribute, the weight vector is $W = (w_1, w_2, \ldots, w_m)$ and $\sum_{j=1}^{m} w_j = 1$.
(1) The standardization of original attributes
The describing ways to variety of attributes, dimensions *etc*. are not standardization for the original attribute value. Therefore, the attributes will be divided into different categories and be standardized in the multi-attribute decision making process. In order to eliminate these differences and facilitate to take a variety of factors into account in decision-making, based on a decision matrix, we first standardize decision attributes. Based on different describing ways, the decision attributes can include the real type and interval-type.
The real type attributes are divided into efficiency and cost type based on different ways to determine values. The efficiency-type attribute is the better, the attribute value the larger, such as available network bandwidth. The cost-type attribute is the better, the attribute value the smaller, such as link loss rate.

Let $y_j^{\max}$ and $y_j^{\min}$ be the maximum and minimum target G_j respectively, the standardized method of the efficiency-type attribute is as follow.

$$Z_{ij} = \frac{y_{ij} - y_j^{\min}}{y_j^{\max} - y_j^{\min}}$$

The standardized method of the cost-type attribute is as follow.

$$Z_{ij} = \frac{y_j^{\max} - y_{ij}}{y_j^{\max} - y_j^{\min}}$$

For interval-type attribute, the attribute have better contribution, attribute value closer to a fixed range. The standardized method of the interval attribute is as follow.

$$Z_{ij} = \begin{cases} 1.0 - \dfrac{q_l - y_{ij}}{\max\{q_l, y_j^{\min}, y_j^{\max} - q_u\}} & (y_{ij} < q_l) \\ 1.0 & (y_{ij} \in [q_l, q_u]) \\ 1.0 - \dfrac{y_{ij} - q_u}{\max\{q_l, y_j^{\min}, y_j^{\max} - q_u\}} & (y_{ij} > q_u) \end{cases}$$

The standardized matrix $Z = (Z_{ij})_{n\times m}$ is non-negative matrix, which is the better if the larger the standardized attribute value is. In order to reflect the user wishes and different service types for the different QoS requirements, we need to compute the product of the weight vector and the standardized matrix, $Z'_{ij} = w_j z_{ij}$, $i = 1, 2, \ldots, m$, $j = 1, 2, \ldots, m$. $Z' = (Z'_{ij})_{n\times m}$ is known as the weighted standardized decision matrix.

(2) The covariance matrix of the weighted standardized decision matrix

In order to extract the principal component, the covariance matrix of $G = \{G_1, G_2, \ldots, G_m\}$ must be obtained. The covariance matrix of Z' is $V = (v_{ij})_{m\times m}$ can be shown as follow.

$$v_{ij} = \frac{1}{n}\sum_{k=1}^{n}(Z'_{ki} - \bar{Z}'_i)(Z'_{kj} - \bar{Z}'_j),\ i, j = 1, 2, \ldots, m. \text{ Here, } \bar{Z}'_j = \frac{1}{n}\sum_{k=1}^{n} Z'_{kj},\ j = 1, 2, \ldots, m.$$

(3) The eigenvalue and eigenvector of V

Since covariance matrix V is positive definite matrix, V has m non-negative eigenvalues which are ordered as $\lambda_1 > \lambda_2 > \ldots > \lambda_m > 0$. The corresponding eigenvectors of the non-negative eigenvalues are $B_1, B_2, \ldots, B_m$. and $B_k = (b_{1k}, b_{2k}, \ldots, b_{mk})^T$, $k = 1, 2, \ldots, m$.

$$\text{Here, } \begin{cases} \sum_{i=1}^{m} b_{ik}^2 = 1 \\ \sum_{i=1}^{m} b_{ik} \cdot b_{il} = 0 \end{cases},\quad k \neq l$$

In other words, the eigenvectors B_1, B_2, …, B_m are mutually orthogonal. The m linearly independent principal components are used to replace the m original correlation assessment objective using principal component analysis. The principal components corresponding with λ_1, λ_2, …, λ_m are represented as $U = \{U_1, U_2, …, U_m\}$. Since $\lambda_1 > \lambda_2 > … > \lambda_m$, U_1, U_2, …, U_m are the first principal component, the second principal component, …, the nth principal component respectively. Here,

$$U_k = \sum_{i=1}^{m} b_{ik} G_i.$$

The attribute weight values of the kth principal component U_k is

$$w_k = \lambda_k \Big/ \sum_{i=1}^{m} \lambda_i .$$

w_k denotes composite attribute weight value of the kth principal component U_k which integrates the original m attribute value. The composite attribute weights are used to represent decision-making role and weight of the principal component.

The cumulative contributive rate of U_1, U_2,…, U_k is $\alpha_k = \sum_{i=1}^{k} \lambda_i \Big/ \sum_{j=1}^{m} \lambda_j$. In this section, we chose first p principal components as the synthetic decision attributes.

The unit eigenvectors of the eigenvalue λ_j include $\pm B_j$, $j = 1, 2, …, m$. In order to make scientific decisions, we need to attach the follow constraints to the unit eigenvectors. With the ideal solution P and negative ideal solution Q are:

$$P = \{\max_j Z'_{ij} \mid i = 1, \ ..., \ n; j = 1, \ ..., \ m\} = \{Z_1^+, Z_2^+, \ ..., \ Z_m^+\},$$
$$Q = \{\min_j Z'_{ij} \mid i = 1, \ ..., \ n; j = 1, \ ..., \ m\} = \{Z_1^-, Z_2^-, \ ..., \ Z_m^-\}.$$

Obviously, no matter which principal component is used to make decisions or evaluation for P and Q, the contribution of the main component must satisfy the condition $U_{P_k} > U_{Q_k}$, that is $\sum_{j=1}^{m} b_{jk} Z_j^+ > \sum_{j=1}^{m} b_{jk} Z_j^-$, $k = 1, 2, …, m$. Thus, the ideal solution is better than negative ideal solution. If the condition is not satisfied, the feature vectors need to be reversed.

The above process transforms m the original dependent parameters $G = \{G_1, G_2, …, G_m\}$ into p independent comprehensive decision parameters $U = \{U_1, U_2, …, U_p\}$, $p < m$. This method can eliminate the interaction among attributes and improve the accuracy of the network selection.

4.3 The Vertical Handoff Decision Algorithm

Based on the principal component extraction method, we proposed a novel vertical handoff decision algorithm which can ensure quality of service and be executed in the terminal. The process is shown in Fig. 2.

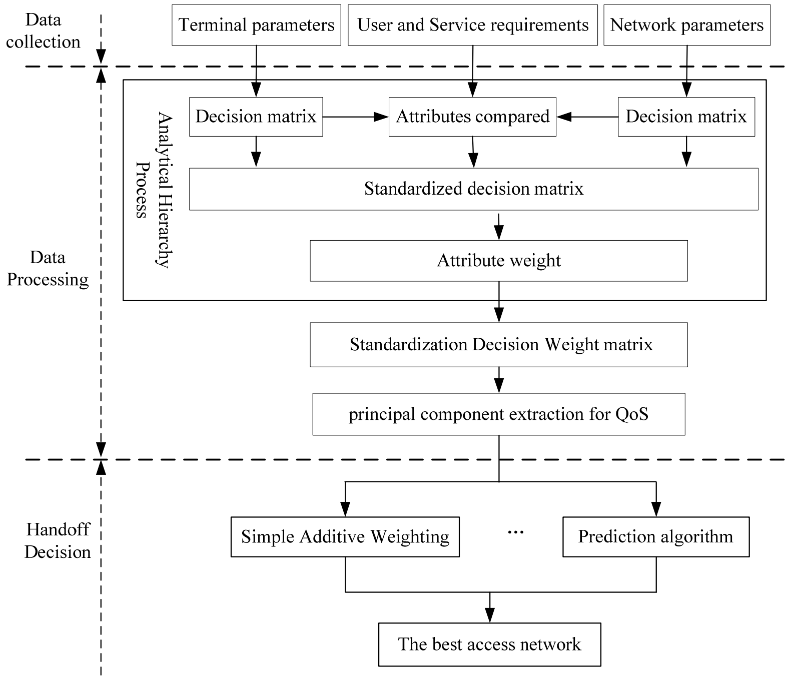

Fig. 2. The vertical handoff algorithm with ensuring QoS.

The proposed vertical handoff decision algorithm consists of three step, data collection, data processing and handoff decision. In the first step, the decision parameters are collected, which include terminal parameters, network parameters, user parameters and service parameters. In the data processing step, the decision matrix is established bases on the collected data which is described in section 3.1. Then, the decision matrix is standardized, the attribute assignment hierarchical tree is established and further the attribute weight values are determined, which is described in section 3.2. Based on the decision matrix and attribute weight values, employing the method proposed in section 4.2, we can get standardization decision weight matrix and extract the principle components for network QoS. In the handoff decision step, compare the QoS of each candidate network by using the available method, such as SAW, and get the optimal access network.

This algorithm establishes QoS criteria from the network related, terminal related, user related and service related attributes, and determines attribute weight values using analytic hierarchy process and extracts principal component using principal component analysis. The optimization target network selection is as follow.

$$A_{opt} = \arg\max_{1\le i\le n}(Q_i)\text{, and } Q_i = \sum_{k=1}^{p}\sum_{j=1}^{m} b_{jk} Z'_{ij}$$

It is noteworthy that, in obtaining the main components of the current QoS attributes, the user can also choose another method to determine the optimal network in the handoff decision step based on the actual network situation and user preferences, such as simple additive weighting, prediction algorithms, and so on.

The proposed algorithm can guarantee the accuracy of the vertical handoff. The available multi-attribute vertical handoff methods which only take the network related parameters into account cannot satisfy the user requirements, since the user's satisfaction degree is the most important for the network QoS. In the proposed algorithm, the network related, terminal related, user related and service related attributes are included, which improves the accuracy of the vertical handoff. Each parameter's contribution to candidate network QoS is determined based on AHP, which can reflect network QoS.

In the multi-attribute vertical handoff decision algorithm, if the more attributes are selected, the selection process will be more complex and the compute cost will also be higher. We make the less independent synthetic attributes to replace the more dependent handoff attributes using principal component analysis. On one hand, the network selection process based on decision algorithm is simple for the less integrated independent attributes; on the other hand, the proposed method can eliminate the interaction among the various attributes and improves the accuracy of the network selection.

To sum up, this proposed method ensures the accuracy of optimal network selection and improve the efficiency of vertical handoff decision in heterogeneous wireless networks.

5. THE ANALYSIS AND VERIFICATION

In this section, the extensive experiment studies are conducted to illustrate the performance improvement of our proposal compared with previous schemes. By using the proposed algorithm, we can ensure the optimal networks (QoS-ensured network) is always selected as access network for the user with special application requirements. As the only a few principal components are employed to decide the QoS-ensured network, our algorithm have the characters of the low complexity and computation cost. At the same time, the principal component analysis can eliminate the interaction among various attributes, such, the proposed algorithm can ensure the accuracy of the network selection.

The simulation environment consists of three WLAN (IEEE 802.11b) access point (AP) and a UMTS base station (BTS), which is a common network structure in the practice network environment, such as in the network hotspots, some users access public network by collaboration of the WLAN with small transmission range but high transmission rate and 3G with large transmission range but low transmission rate. The UMTS covers the entire network area and the WLAN-1, WLAN-2 and WLAN-3 cover a smaller area respectively. The network environment is shown in Fig. 4. In simulation, a mobile user moves from left to right with the speed of $1m/s$ along a line from point A to G, which at point A at starting time, at point G at end time. The proposed algorithm is compared with simple additive weighting and gray correlation analysis in the vertical handoff process.

5.1 The Principal Component Analysis

(1) The establishment of multi-attribute criteria

The common network parameters are selected in simulation, which include network availability ρ, throughput α, the factor of network time β (consist of delay τ, response time η, jitter θ), the factor of reliability (consist of bit error rate λ, burst error μ, average number of retransmissions per packet v, packet loss rate σ), the network security δ, access cost ε. Actual measurement results of parameters of WLAN and UMTS are referred to set candidate network QoS parameters, which are given in Table 1.

Table 1. The network QoS parameters.

QoS parameter		UMTS	WLAN-1	WLAN-2	WLAN-3
α (*Mb/s*)		1.7	25	20	25
β	τ (*ms*)	19	30	45	50
	η (*ms*)	9	30	28	30
	θ (*ms*)	6	10	10	10
γ	λ (*dB*)	10-3	10-5	10-5	10-6
	μ	0.5	0.2	0.25	0.2
	v	0.4	0.2	0.3	0.2
	σ	0.07	0.04	0.04	0.06
δ (*level*)		8	7	6.5	6
ρ (*dBi*)		70	60	60	65
ε (*per kbyte*)		0.9	0.2	0.1	0.2

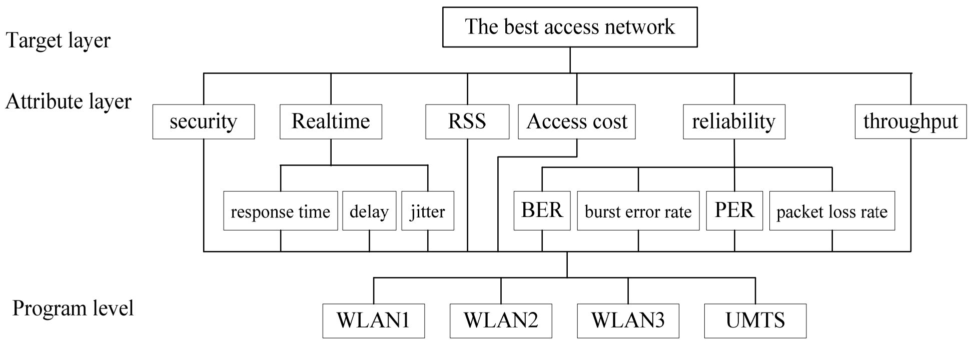

Fig. 3. The attribute hierarchical structure tree.

From the Table 1, we have the decision matrix and can get determine attribute weights for current network using AHP described in section 3.2. Then, the decision matrix is standardized, the attribute assignment hierarchical tree is established which is shown in Fig. 3. Based on the decision matrix and attribute weight values, employing the method proposed in section 4.2, we can get standardization decision weight matrix, which is shown in Table 2.

(2) The vertical handoff decision and analysis

Based on the standardized QoS parameters and their weight, we can extract the principle components for networks QoS by employing the method proposed in section 4.2. We first gain the covariance matrix of the weighted standardized decision matrix and its eigenvalues and eigenvectors. The eigenvalues are as follow.

$$LATENT = |0.0326, 0.0038, 0.0006, 0, 0, 0, 0, 0, 0, 0|^T$$

Table 2. The standardized QoS parameters and their weight.

QoS parameter		UMTS	WLAN-1	WLAN-2	WLAN-3	Weight
α		0	1	0.7854	1	0.30
β	τ	1	0.6452	0.1613	0	0.02
	η	1	0	0.0952	0	0.02
	θ	1	0	0	0	0.01
γ	λ	0	0.9910	0.9910	1	0.07
	μ	0	1	0.8333	1	0.05
	v	0	1	0.5	1	0.03
	σ	0	1	1	0.3333	0.14
δ		1	0.5	0.25	0	0.11
ρ		1	0	0	0.5	0.15
ε		0	0.875	1	0.875	0.10

The first three principal components cover the main QoS information by observing the eigenvalues. After a principal component extraction, the weights of the eleven main components of the original attributes are shown as follow.

$$\text{Score} = \begin{array}{ccccccccccc} -0.0790 & -0.0416 & 0.1013 & 0.0390 & 0.0200 & 0.0088 & 0.0491 & 0.0756 & -0.0167 & 0.0703 & 0.0437 \\ 0.3084 & -0.0133 & 0.1270 & 0.0390 & 0.0200 & 0.0088 & 0.0491 & 0.0756 & -0.0167 & 0.0703 & 0.0437 \\ 0.2655 & 0.0051 & 0.0698 & 0.0390 & 0.0200 & 0.0088 & 0.0491 & 0.0756 & -0.0167 & 0.0703 & 0.0437 \\ 0.2648 & -0.1334 & 0.0926 & 0.0390 & 0.0200 & 0.0088 & 0.0491 & 0.0756 & -0.0167 & 0.0703 & 0.0437 \end{array}$$

The columns from right to left are the first to eleventh principal component respectively. The rows from top to bottom represent the network UMTS, WLAN1, WLAN2 and WLAN3. The proposed algorithm is used for vertical handoff decision, and the result to select all eleven main components is consistent with that of the first three principal components. The priority access order to candidate networks is:

$$WLAN-1 \succ\succ WLAN-2 \succ\succ WLAN-3 \succ\succ UMTS.$$

Notice if the cumulative contributive rate is more than 80%, the composite principal components can replace the original attributes to choose the access networks. Through the analysis above, the decision-making result to choose the first three principal components is consistent with that of all eleven main components, while our algorithm is sample and low computation cost.

5.2 Comparative Analysis of PCA, SAW and GRA

In the network environment in section 5.1, when user moves from point *A* to point *G*, the proposed method, SAW and GRA, are used to make decision for vertical handoff. The simulation results are shown in Fig. 4.

We notice that the handoff frequency of the proposed algorithm is less than that of SAW and GRA in the case that the network QoS is guaranteed. In our algorithm, the de-

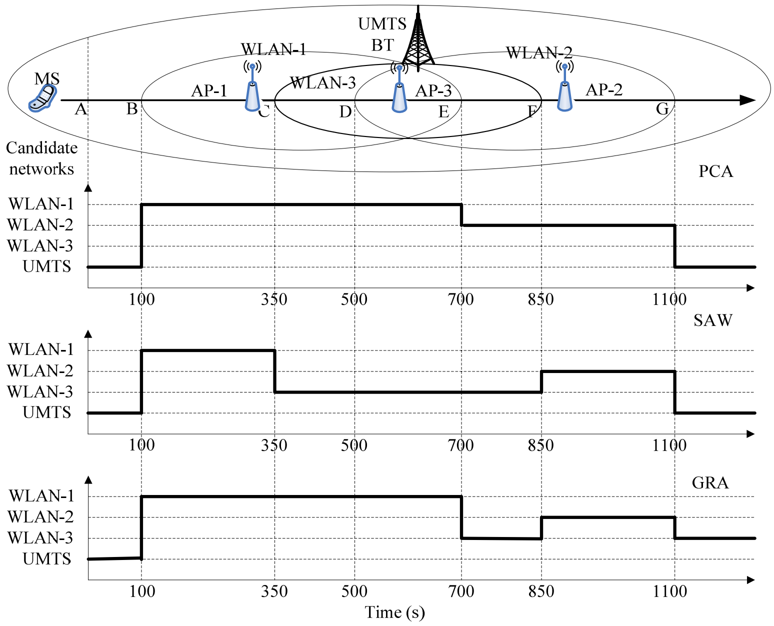

Fig. 4. Simulation environment and results.

cision-making accuracy and computation cost depends on the number of principal components involved in handoff decision. There is a tradeoff between the decision accuracy and computation cost of the network selection. In theory, if the more principal components are selected, the calculation will be more complex which results in the more accurate decision.

We determine the order of the selected networks by apply the proposed algorithm. Each principal component contains the contributive contribution of the original attributes. Notice the first few principal components often contain most all original attributes. Therefore, we only choose the first few principal components to select networks, which ensure the accuracy of the network selection with small computation cost. Typically, the selected principal components contains 80% contribution of the original attributes, the handoff decision is available.

In section 4, the covariance matrix V is positive definite matrix, and has m non-negative eigenvalues which are ordered as $\lambda_1 > \lambda_2 > \ldots > \lambda_m > 0$. The principal components corresponded with $\lambda_1, \lambda_2, \ldots, \lambda_m$ are represented as $U = \{U_1, U_2, \ldots, U_m\}$. We assume that $O(U_i)$ is the contributive proportion of the principal component U_i, $i = 1, 2, \ldots, m$. Since $\lambda_1 > \lambda_2 > \ldots > \lambda_m$, we can gain $O(U_1) > O(U_2) > \ldots > O(U_m)$. Because the eigenvectors $B_1, B_2, \ldots, B_m$ are mutually orthogonal, there are no interaction among $O(U_1)$, $O(U_2), \ldots, O(U_m)$.

In the network environment described in section 4, the contributive rate of the first principal component is 87%, and the contributive rate of the second principal component is 11%, that is, the total contributive rate of the first two principal components is 98%. The proposed algorithm can grasp the impact the main QoS information. The first two principal components are shown in Figs. 5 and 6.

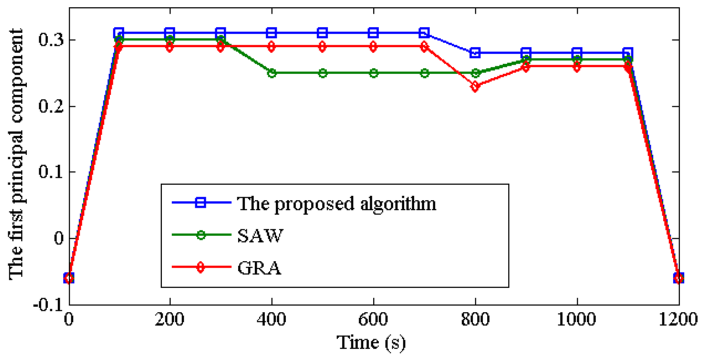

Fig. 5. The first principal component.

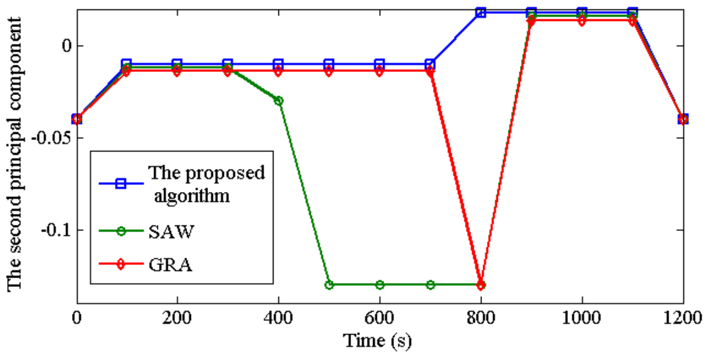

Fig. 6. The second principal component.

The proposed vertical handoff decision method can extract the principal components, and effectively eliminate the interaction among the original decision attributes. Thus, the proposed algorithm can accurately select the QoS-ensured network only employing fewer principal components. Compared to SAW and GRA, the principal component analysis has a better performance to determine the network QoS by only using the first two principal components of QoS.

The above analysis shows the proposed vertical handoff decision algorithm can provide high network selection accuracy in the vertical handoff process, which is suitable for heterogeneous wireless networks.

6. CONCLUSION

In integration wireless system, the efficient vertical handoff management in heterogeneous wireless networks is critical to improve the system performance. In handoff decision phase, the mobile device determines which network it should be connected to. The network selection algorithm is a key issue in the vertical handoff decision phase. This paper considers how to merge multiple parameters which include terminal parameters, network parameters, user parameters and service parameters, and select an optimal access network. A method to determine weight value of each attribute proposed according to the important degree of each parameter. In order to eliminate the interaction among various criteria, we propose a novel principal component extraction method employing principal component analysis. Only using less of the synthetic components, we can rapidly select the QoS-ensured network with lower compute cost.

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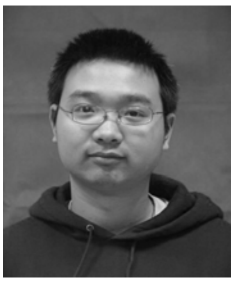

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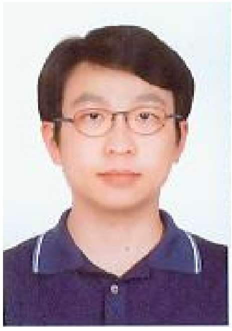

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