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Methods of Cloud-path Selection for Offloading in Mobile Cloud Computing Systems

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***Abstract*—Recently, there emerge a variety of clouds in sky and thus, several similar cloud services (from different cloud venders) can be provided to a mobile end device. The goal of cloud-path selection is to find an optimal cloud among a certain class of clouds that provide the same service, in order to carry out the offloaded computation tasks. It is easy to choose the optimal cloud to save execution time incurred by offloading to cloud when considering only one factor. However, there are many criteria such as speed, bandwidth, price, security and availability that need to be considered when making final decisions. In this paper, a multiple criteria decision analysis approach based on the analytic hierarchy process (AHP) and the technique for order preference by similarity to ideal solution (TOPSIS) in a fuzzy environment is proposed to decide which cloud is the most suitable one for offloading. The AHP is used to determine the weights of the criteria for cloud-path selection, while fuzzy TOPSIS is to obtain the final ranking of alternative clouds. The numerical analysis is performed to evaluate the model.**

***Index Terms*—cloud computing; offloading; selection; AHP; TOPSIS**

I. Introduction

Along with the development of cloud computing [1], offloading has become a much more attractive way to extend the battery life and reduce execution time on mobile devices. But there are a large number of clouds appearing in sky with different charging and condition, and offloading the same program to different clouds may perform different amounts of computing within the same duration due to the cloud's speeds, and may cost different communication time due to bandwidth and cloud's availability. Therefore, an optimal cloud-path selection method is needed when choosing the best cloud.

The selection process can be a hard task since a variety of data need to be analyzed and many factors need to be considered. AHP and fuzzy TOPSIS are ideal ways to do multiple criteria decision-making [2].

Accordingly, the main contributions of this study are two-fold. Firstly, we present the optimal cloud selection architecture and algorithms based on one criterion each time. Secondly, in order to make decision when considering multiple criteria simultaneously, we combine the methods of AHP and fuzzy TOPSIS.

The remainder of this paper is structured as follows. Section II presents the problem of how to make decision in cloud-path selection based on one or many criteria. Section III briefly introduces the methods of AHP and fuzzy TOPSIS. A cloud-path selection scheme that using the methods of AHP and fuzzy TOPSIS is proposed and analyzed in Section IV. Section V concludes the paper.

II. Problem definition

A. System overview

In cloud offloading systems, in order to reduce total application execution time, we need to find the optimal cloud-path pair that from the mobile devices to the cloud to carry out the offloaded computation. The network bandwidth, the server's speedup, the link's failure rate and cloud's condition should be considered when selecting a server in cloud.

There are a variety of clouds appearing these days, for example, Amazon EC2 [3], Microsoft Windows Azure [4], Google App Engine [5], IBM Blue Cloud [6] and so on, but since they provide different kinds of cloud services that shall not be comparable. Here, we consider a certain class of clouds that provide the same service. A more suitable example will be the peer cloud storage services such as Dropbox, Box, Apple iCloud [7], MS Skydrive, Google Drive and so on.

The servers on clouds could also be different from each other, but basically the more resources they provide (larger speedup value F), the higher it costs. Therefore, we assume F is proportional to the cost per unit C, which means the larger F is, the more cost it would be, and thus we have

$$C_i = k_i F_i \tag{1}$$

where k_i is the scale factor for the i^{th} cloud, the speedup F_i indicates how powerful the i^{th} cloud server is in terms of execution speed comparing with the mobile device. Normally, F_i is much larger than 1 due to the servers are resource-rich while the mobile devices are resource-limited.

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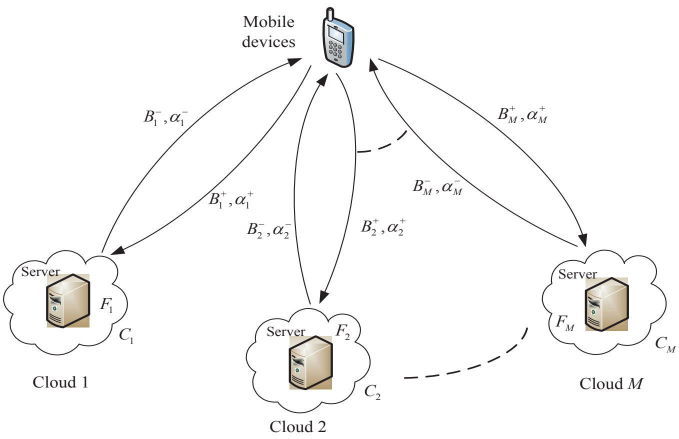

Fig. 1. Diagram of cloud offloading systems

The diagram of cloud offloading systems is illustrated in Fig.1. There are M alternative clouds in the sky with a variety of speedup factors and economy costs. And bandwidth and link's failure rate are also different from each other. Therefore, an optimal cloud-path from the mobile device to cloud needs to be selected.

TABLE I
PARAMETERS OF OFFLOADING

Symbol	Meaning
B_i^+	uplink bandwidth
B_i^-	downlink bandwidth
D_i^+	uplink exchanged data
D_i^-	downlink exchanged data
t_m	execution time on the mobile device
t_s	execution time incurred by offloading
α_i^+	uplink failure rate
α_i^-	downlink failure rate
F_i	speedup factor
C_i	economy cost

The time incurred by offloading is the sum of communication time and computing time spent on the server in cloud and it should be smaller than the execution time required by the mobile device in order to improve performance.

Therefore, for a certain cloud-path such as from the mobile device to cloud i, offloading program to the cloud saves time only if it meets the following condition [8]

$$t_m > t_s = \frac{t_m}{F_i} + (1+\alpha_i^+) \cdot \frac{D_i^+}{B_i^+} + (1+\alpha_i^-) \cdot \frac{D_i^-}{B_i^-} \quad (2)$$

where $i \in 1, 2, \cdots M$, $\frac{t_m}{F_i}$ is the time spent on cloud, $(1+\alpha_i^+) \cdot \frac{D_i^+}{B_i^+} + (1+\alpha_i^-) \cdot \frac{D_i^-}{B_i^-}$ is the communication time in serial when considering the link's failure, the parameters used in offloading process are given in Table I. Note that bandwidth and link's failure rate for the uplink and downlink can be different, i.e. $B_i^+ \neq B_i^-$ and $\alpha_i^+ \neq \alpha_i^-$.

If economy cost is taken into consideration, the best cloud-path pair is selected when it meets the following condition

$$min \left[k_i \cdot \frac{t_m}{C_i} + (1+\alpha_i^+) \cdot \frac{D_i^+}{B_i^+} + (1+\alpha_i^-) \cdot \frac{D_i^-}{B_i^-} \right] \quad (3)$$

There are many principles [9] to determine the optimal cloud-path pair, such as

1) *Random:* Select the cloud-path pair randomly.

2) *Bandwidth:* Choose the cloud-path pair with the highest bandwidth.

3) *Link's failure rate:* Select the cloud-path pair with the lowest link failure rate.

4) *Speedup factor:* Select the cloud-path pair with the highest speedup factor.

5) *Cost:* Select the cloud-path pair with the lowest economy cost.

B. Simulation and performance evaluation

In this section, we implement above algorithms to make cloud-path decision and compare the numerical results.

Following parameters are used: The bandwidth B_i is uniformly chosen from $[32kb/s, 256kb/s]$ and the link's failure rate α_i is uniformly chosen from [0.01, 0.2]. Note that the bandwidth and link's failure for uplink and downlink can be different. The exchanged data for uplink and downlink are fixed as $D_i^+ = 2000kb$ and $D_i^- = 1500kb$, respectively.

For convenience, we assume k_i is a constant and set as 1. The speedup factor F_i is uniformly chosen from [2, 20]. The baseline execution time is varying from 10s to 200s. And the number of alternative clouds is 10. We run the simulation 10000 times.

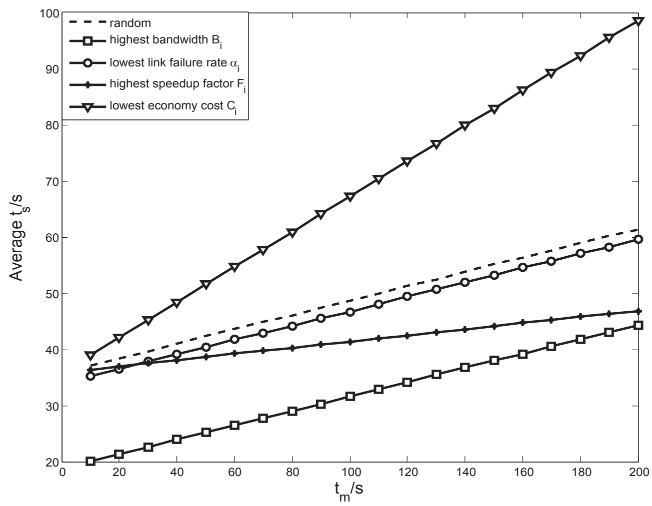

Fig. 2. Average t_s under different cloud-selection algorithms

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The average time t_s obtained by the five cloud-selection algorithms are depicted in Fig.2. It can be seen that the random algorithm costs much more time than the algorithms of highest bandwidth, lowest link failure rate and highest speedup factor due to it does not consider any network or cloud condition. The lowest economy cost algorithm gets the biggest t_s among the five cases due to it is the cost criteria while the highest bandwidth, lowest link's failure rate and highest speedup factor are benefit criteria.

Besides, according to the improvement of average time t_s, we can rank the priory of importance for the three benefit criteria mentioned above as bandwidth > speedup factor > link failure rate.

C. Cloud-path selection problem

Kumar ranked servers based on energy savings for computation offloading in [10]. From above analysis, it can be found that our analysis is also limited in one criterion when making decision in selecting the best cloud-path, without considering other factors at the same time.

However, there are many criteria needed to be considered simultaneously such as

1) Bandwidth: depends on the wireless link between the mobile devices and cloud. When the wireless connection is excellent, a large amount of application execution and data could be offloaded to the cloud, but when it is poor, only a small amount of application execution and data can be offloaded during limited time [11].

2) Price: how much it costs for the same amount of computing and it various in different cloud services. For the mobile cloud service providers, how to build an economic service provisioning scheme is critical for mobile cloud service providers, particularly when the mobile cloud resource is restricted [12].

3) Speed: how fast a server on cloud for computing is. Relatively, we can measure it though speedup factor F, which compares the execution speed of cloud to that of mobile device.

4) Security: or privacy, first of all, shifting all data and computing resources to the cloud is dangerous, for example, tracking individuals through location-based navigation data offloaded to the cloud. Besides, security and privacy settings depend on the cloud provides, due to the data is stored and managed in the cloud [8].

5) Availability: it is related with link's failure and cloud's unavailability during the whole offloading process. Failures may occur due to the mobile nature of mobile devices and unstable connectivity of wireless links, which render a less predictability of the performance of a program running under the control of offloading systems [13].

Therefore, the decision hierarchy for the problem of cloud selection is formed as Fig.3 when these criteria are included.

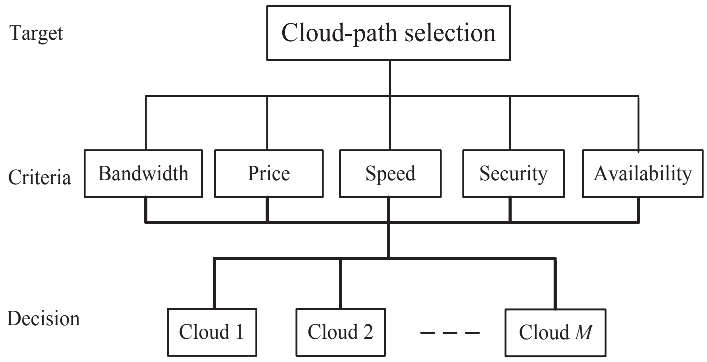

Fig. 3. The decision hierarchy of cloud selection

There are three hierarchies listed in Fig.3. The first level is called target hierarchy, meaning what we want to do and what the object is. The second level is called criteria hierarchy, and there are five criteria to be considered for this problem of cloud-path selection. The last level is decision hierarchy, in which we can make the final decision in choosing one of the alternative clouds based on the analysis in criteria hierarchy.

III. Methods of AHP and fuzzy TOPSIS

To rank the cloud-path pairs, the methods of AHP and fuzzy TOPSIS are combined in this paper. AHP is employed to obtain weights of the criteria for cloud-path selection, while fuzzy TOPSIS is used to determine the priorities of the alternative clouds in decision-making process [14].

A. The AHP method

AHP is a process for determining the relative importance of a set of alternatives in a multi-criteria decision problem. It converts the evaluations to numerical values that can be processed and compared and derives a numerical weight or priority for each element of the hierarchy.

The results of the pairwise comparison on N criteria can be expressed in an evaluation matrix as

$$\mathbf{A} = (a_{ij})_{N\times N} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1N} \\ a_{21} & a_{22} & \cdots & a_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ a_{N1} & a_{N2} & \cdots & a_{NN} \end{bmatrix}, a_{ii} = 1, a_{ji} = 1/a_{ij}$$

where element a_{ij} is based on a standardized comparison scale of nine levels as shown in Table II [2].

The relative weights are given by eigenvector ($\mathbf{w}$) corresponding to the largest eigenvalue (λ_{max}) as follows

$$\mathbf{A}\mathbf{w} = \lambda_{max}\mathbf{w} \quad (4)$$

The output of AHP is strictly related to the consistency of the pairwise comparison. The consistency index (CI) is

$$\text{CI} = \frac{\lambda_{max} - n}{n - 1} \quad (5)$$

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TABLE II
IMPORTANCE SCALE AND ITS DEFINITION

Definition	Intensity of importance
Equally important	1
Moderately more important	3
Strongly more important	5
Very strongly more important	7
Extremely more important	9
Intermediate	2,4,6,8

The final consistency ratio (CR) is calculated as

$$\mathrm{CR} = \mathrm{CI}/\mathrm{RI} \tag{6}$$

and in order to meet the consistency, it must be less than 0.1.

B. *The fuzzy TOPSIS method*

TOPSIS is widely used to solve decision problems in real situation. We use fuzzy TOPSIS here since it is intuitively easy for the decision-makers to use and calculate through a triangular fuzzy number and it is proved to be an effective way for formulating decision problems [14]. The process steps of fuzzy TOPSIS can be outlined as follows [2].

1) Establish a decision matrix for the ranking: The structure of the matrix can be expressed as follows.

$$\mathbf{X} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_i \\ \vdots \\ A_M \end{array} \begin{array}{c} \begin{array}{cccccc} C_1 & C_2 & \cdots & C_j & \cdots & C_N \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1j} & \cdots & x_{1N} \\ x_{21} & x_{22} & \cdots & x_{2j} & \cdots & x_{2N} \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{ij} & \cdots & x_{iN} \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ x_{M1} & x_{M2} & \cdots & x_{Mj} & \cdots & x_{MN} \end{bmatrix} \end{array}$$

where C_j is a criterion and A_i is one of alternatives, N is the number of criteria and M is the number of alternatives. The triangular fuzzy number x_{ij} belong to [0, 1] and thus, there is no need for normalization. The membership functions of linguistic values used in this paper are described in Fig.4, and the corresponding triangular fuzzy numbers are shown in Table III.

2) Calculate the weighted normalized decision matrix:

$$v_{ij} = x_{ij} \times w_j, \quad i = 1, 2, \cdots, M \quad j = 1, 2, \cdots, N \tag{7}$$

where w_j represents the weight of the j^{th} criterion, which is obtained from the AHP method.

3) Determine the positive-ideal (A^+) and negative-ideal solutions (A^-), respectively:

$$\begin{aligned} A^+ &= \{v_1^+, v_2^+, \cdots, v_N^+\} \\ &= \left\{ \left(\max_j v_{ij} | i \in I \right), \left(\min_j v_{ij} | i \in I' \right) \right\} \end{aligned} \tag{8}$$

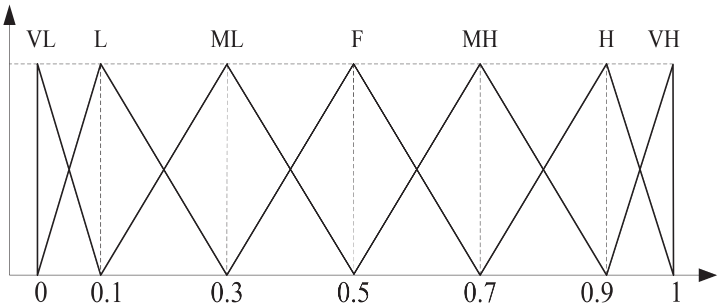

Fig. 4. Membership functions of linguistic values

TABLE III
FUZZY MEMBERSHIP FUNCTIONS

Linguistic values	Fuzzy ranges
Very low(VL)	(0,0,0.1)
Low(L)	(0,0.1,0.3)
Medium low(ML)	(0.1,0.3,0.5)
Fair(F)	(0.3,0.5,0.7)
Medium high(MH)	(0.5,0.7,0.9)
High(H)	(0.7,0.9,1)
Very high(VH)	(0.9,1,1)

$$\begin{aligned} A^- &= \{v_1^-, v_2^-, \cdots, v_N^-\} \\ &= \left\{ \left(\min_j v_{ij} | i \in I \right), \left(\max_j v_{ij} | i \in I' \right) \right\} \end{aligned} \tag{9}$$

For normalized positive triangular numbers, we can define the fuzzy positive-ideal and negative-ideal solutions. As for benefit criterion, we have $v_j^+ = (1, 1, 1)$ and $v_j^- = (0, 0, 0)$, while for cost criterion, $v_j^+ = (0, 0, 0)$ and $v_j^- = (1, 1, 1)$.

4) Calculate the distance of each alternative from A^+ and A^- using the Euclidean distance:

$$D_i^+ = \sum_{j=1}^{N} d(v_{ij}, v_j^+), \quad i = 1, 2, \cdots, M \tag{10}$$

$$D_i^- = \sum_{j=1}^{N} d(v_{ij}, v_j^-), \quad i = 1, 2, \cdots, M \tag{11}$$

5) Calculate the relative closeness to ideal solution:

$$C_i^* = \frac{D_i^-}{D_i^+ + D_i^-} \tag{12}$$

6) Rank the alternatives according to C_i^* in descending order:

IV. CLOUD-PATH SELECTION

A. *Calculate the weights of criteria*

The priory of importance depends on what we care about most. For instance, if the offload data is neither privacy nor confidential, in this case, security is the least important factor

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among the five criteria.

For a cloud offloading system, speed is considered the most significant because it saves execution time and bandwidth is also important since it decides the extra communication cost between mobile devices and cloud. According to the simulation results for individual criterion depicted in Fig.2, we assume the priory of importance is ranked as: bandwidth > speed > availability > security > price when choosing the optimal cloud-path pair. However, the priority of these five criteria can be various in other situations.

Employing the importance scale given in Table II, we get the pairwise comparison matrix as shown in Table IV.

TABLE IV
PAIRWISE COMPARISON MATRIX FOR CRITERIA

Criteria	bandwidth	price	speed	security	availability
bandwidth	1	9	3	7	5
price	1/9	1	1/6	1/2	1/3
speed	1/3	6	1	4	3
security	1/7	2	1/4	1	1/2
availability	1/5	3	1/3	2	1

By using the AHP method, we calculate the weights of the criteria as shown in Table V. The weights will be further used in evaluation process.

TABLE V
RESULTS OBTAINED FROM AHP

Criteria	Weights	λ_{max},CI,RI	CR
bandwidth	0.528	λ_{max}=5.089 CI=0.022 RI=1.12	0.020
price	0.042		
speed	0.252		
security	0.068		
availability	0.110		

From Table V, it can be seen that speed and bandwidth are determined as the most important criteria. Besides, the consistency ratio CR is $0.020 < 0.1$ (criteria checking point). Thus, the weights are shown to be consistent which can be used in the decision-making process.

B. Select the optimal cloud-path

In this problem of cloud selection, it can be seen that price is a cost criterion whereas the others are benefit criteria. The results of fuzzy weighted decision matrix are given in Table VI.

The results of fuzzy TOPSIS analysis are summarized in Table VII. D_i^+ and D_i^- can be calculated by using Eq.10 and Eq.11. Based on C_i^* values, the ranking of the clouds in descending order are cloud 2, cloud 4, cloud 3 and cloud 1 as shown in Fig.5. And thus, cloud 2 with $C_i^* = 0.348$ is the optimal alternative among the four clouds. In other words, we should choose cloud 2 to offload data when considering the five criteria simultaneously.

TABLE VII
FUZZY TOPSIS RESULTS

Alternatives	D_i^+	D_i^-	C_i^*
cloud 1	3.802	1.225	0.244
cloud 2	3.267	1.743	0.348
cloud 3	3.402	1.624	0.323
cloud 4	3.365	1.662	0.331

According to the numerical analysis, the method of combing AHP and fuzzy TOPSIS seems to be an effective and synthesized way in solving cloud-path selection. However, the challenge we face today is that those parameters for decision making such as bandwidth, security, execution time for offloading and failure rate are a little hard to measure or acquire timely in practical systems. Therefore, the way how to estimate and measure these parameters need to be further investigated in our future study.

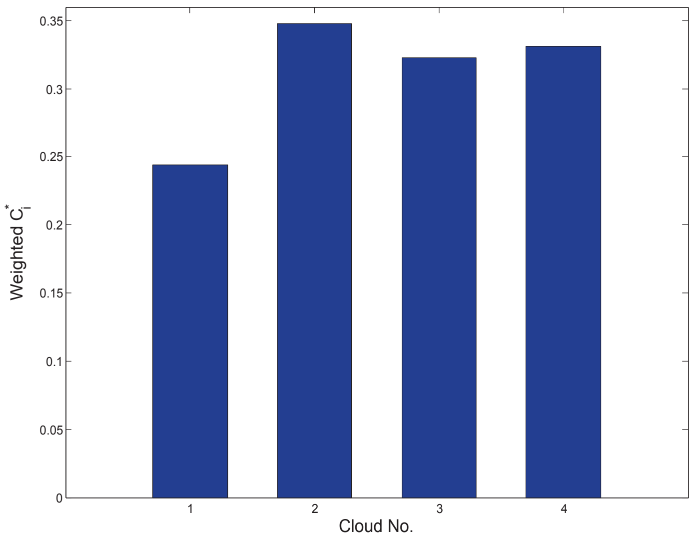

Fig. 5. The decision hierarchy of cloud selection

V. CONCLUSION

To sum up, the traditional algorithms of server selection on cloud are limited only on one criterion. However, in this study, several alternative clouds are considered and evaluated in terms of many different criteria such as speed, bandwidth, security, price and availability in selection problem.

We use a scheme that combing AHP and fuzzy TOPSIS methods, which considering the subjective judgments of evaluators and making final decision based on the results from multiple criteria analysis to select an optimal cloud-path in cloud offloading systems. And it is provided to be an effective and synthesized way through numerical analysis. Besides, both single and multiple criteria decision analysis

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TABLE VI
WEIGHTED EVALUATION MATRIX FOR THE ALTERNATIVE CLOUDS

Cloud	Bandwidth	Price	Speed	Security	Availability
cloud 1	VL	H	MH	L	ML
cloud 2	VH	H	VH	VL	L
cloud 3	F	ML	H	H	MH
cloud 4	MH	L	F	MH	VH
cloud 1	(0, 0, 0.1)	(0.7, 0.9, 1)	(0.5, 0.7, 0.9)	(0, 0.1, 0.3)	(0.1, 0.3, 0.5)
cloud 2	(0.9, 1, 1)	(0.7, 0.9, 1)	(0.9, 1, 1)	(0, 0, 0.1)	(0, 0.1, 0.3)
cloud 3	(0.3, 0.5, 0.7)	(0.1, 0.3, 0.5)	(0.7, 0.9, 1)	(0.7, 0.9, 1)	(0.5, 0.7, 0.9)
cloud 4	(0.5, 0.7, 0.9)	(0, 0.1, 0.3)	(0.3, 0.5, 0.7)	(0.5, 0.7, 0.9)	(0.9, 1, 1)
Weight	0.528	0.042	0.252	0.068	0.110
cloud 1	(0, 0, 0.053)	(0.029,0.038, 0.042)	(0.126, 0.176, 0.227)	(0, 0.007, 0.020)	(0.011, 0.033, 0.055)
cloud 2	(0.475, 0.528, 0.528)	(0.029,0.038, 0.042)	(0.227, 0.252, 0.252)	(0, 0, 0.007)	(0, 0.011, 0.033)
cloud 3	(0.158, 0.264, 0.370)	(0.004,0.013, 0.021)	(0.176, 0.227, 0.252)	(0.048, 0.061, 0.068)	(0.055, 0.077, 0.099)
cloud 4	(0.264, 0.370, 0.475)	(0, 0.004, 0.013)	(0.076, 0.126, 0.176)	(0.034, 0.048, 0.061)	(0.099, 0.110, 0.110)
A^+	$v_1^+ = (1,1,1)$	$v_2^+ = (0,0,0)$	$v_3^+ = (1,1,1)$	$v_4^+ = (1,1,1)$	$v_5^+ = (1,1,1)$
A^-	$v_1^- = (0,0,0)$	$v_2^- = (1,1,1)$	$v_3^- = (0,0,0)$	$v_4^- = (0,0,0)$	$v_5^- = (0,0,0)$

approach are performed.

In short, cloud-path choosing will be a crucial issue due to the development of mobile cloud computing. This paper aims in offering a solution to cloud-path choosing while multi-criteria are being considered, and the aim hits the trend of future realistic needs.

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