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Hybrid multi criteria decision methods for optimal cloud selection in mobile cloud computing

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ABSTRACT

Cloud computing provides the users with flexibility of using computational systems on demand at nominal cost. Execution of resource intensive task on mobile devices is still a big challenge due to resource constraints of mobile devices. Utilizing the services of resource rich cloud servers for offloading the task from mobile device can overcome the resource constraint issues of mobile devices. When offloading the task, there is a need to choose an optimal cloud server from a pool of available cloud servers offering similar services. The proposed work uses three hybrid multicriteria decision methods for choosing the optimal cloud server and comparative analysis of the three methods are presented. Real time cloud servers located at four different regions are considered with six quality of service (QoS) attributes. The results indicate that all the three methods are viable solutions in selecting the optimal cloud server with multi-objective optimization on the basis of ratio analysis (MOORA) providing a faster response compared to other two methods. Sensitivity analysis performed proves the correctness and effectiveness of the proposed methodology.

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1. INTRODUCTION

With advancement of technology, mobile computing is more preferred than traditional systems. Limited battery power and processing capabilities are still drawbacks of mobile devices. Cloud computing emerged as a solution for light weight portable devices by providing anything and everything from computing infrastructure to applications delivered as a service to the end user. Cloud computing is a distributed paradigm where resources are provided with option of pay as per usage and on-demand. It is an internet-based paradigm which provides computing, storage and service solutions [1]-[3].

Cloud computing is one of the feasible solutions to address few of the challenges faced by mobile devices. The term mobile cloud computing (MCC) was coined by integrating mobile devices with cloud computing. MCC is a distributed paradigm consisting of mobile computing, cloud computing and network [4], [5]. The main aim of MCC is to improve the processing capability of mobile devices by offloading the computationally intensive task to resource rich cloud servers. Based on the intensity of computation involved in an application, the decision needs to be taken whether to offload or not considering various parameters like network characteristics, size of the task and data to be transferred [6]-[11].

With increased growth of internet of things (IoT) devices and mobile computing, there is a need for offloading the resource intensive task to cloud servers. Choosing an optimal cloud server among a class of available cloud servers is a challenging task and is an area of research to be further explored. Delay sensitive applications require minimum response time and hence choosing an optimal cloud is necessary. Multi criteria decision analysis (MCDA) is one of the vital techniques applied in several domains for choosing an ideal solution from a set of alternatives with conflicting criteria. MCDA techniques can be applied in choosing an optimal cloud from a class of cloud servers offering similar services [12].

MCDA involves three main components, firstly the alternatives to be ranked, secondly the criteria used to compare and evaluate the alternatives and thirdly, the weights to specify the significance of each criterion based on the decision maker's preference. The criteria can be either qualitative or quantitative based on MCDA method. It is important to choose the right criteria and accurate weights for each criterion since different weights can result in different ranking of the alternatives [13], [14].

Kumar and Kumar [15] proposed a method for identifying the best cloud service provider using analytical hierarchical process (AHP) for calculating weights and similarity to ideal solution (TOPSIS) for ranking the cloud servers. Malhotra *et al.* [16] discusses on choosing the best cloud service provider using integer multiplication. A comparison between integer multiplication and geometric mean method is carried out. Wu *et al.* [17] uses AHP and TOPSIS in fuzzy environment to choose an optimal cloud for mobile cloud environment. Goudarzi *et al.* [18] discusses the usage of genetic algorithm to select the ideal alternative in a multisite environment while offloading the computationally intensive task in mobile cloud computing. Singla and Kaushal [19] suggests the usage of fuzzy AHP to identify the best cloud server from a class of cloud servers in a mobile cloud computing environment. Chauhan *et al.* [20] implements weighted sum model, fuzzy AHP and fuzzy revised AHP to identify the best cloud service provider. Basu and Ghosh [21] discusses the usage of fuzzy TOPSIS in selecting the cloud service providers considering three cloud service providers as the alternative and nine criteria. Fuzzy TOPSIS is further used in determining the best cloud type considering three cloud types: public, private and hybrid. Researchers [22]-[24] emphasize on ranking the best cloud service providers like Amazon, Google, and Microsoft. It is seen in literature review that most of the techniques were used in choosing the best cloud service providers. In the proposed work, a faster and new approach of cloud path selection in mobile cloud computing environment is presented using hybrid MCDA techniques.

The proposed work focuses on selecting an optimal cloud server from a class of available cloud servers offering similar services in mobile cloud computing environment. When offloading the task from mobile device to the cloud server, the proposed article chooses an optimal cloud server for offloading. In this work, four cloud servers located at different regions and six quality of service (QoS) attributes are considered. Three different experiments are performed for selecting the optimal cloud server. In the first experiment, AHP is used to compute criteria weights using pairwise comparison. Criteria weights obtained using AHP are used by technique for order preference by TOPSIS to rank the cloud servers. In the second experiment, the criteria weights obtained using AHP are used by preference ranking organization method for enrichment of evaluations (PROMETHEE II) to rank the cloud servers. In third experiment, the criteria weights obtained using AHP are used by multi-objective optimization on the basis of ratio analysis (MOORA) to rank the cloud servers. Comparative analysis on the results obtained by the three methods is presented and sensitivity analysis is performed to prove the robustness and consistency of the proposed work.

The key contributions of this article are summarized as following:

- Techniques for selecting an optimal cloud server from a class of cloud servers offering similar services are implemented in a mobile cloud computing environment using three different hybrid MCDA techniques TOPSIS, PROMETHEE II and MOORA along with AHP. All the three methods proved to be viable solutions in selecting the optimal cloud.
- PROMETHEE II and MOORA are the two new approaches proposed in selecting the optimal cloud server. The results indicate that both these methods are faster compared to existing method TOPSIS [25].
- Real time values are assigned to the criteria for cloud service selection after performing the experiments on a test bed with various runs on four cloud servers located in different regions.
- Efficacy and correctness of the proposed algorithms are validated by performing sensitivity analysis.

2. RESEARCH METHOD

In the proposed work, four cloud servers located at different regions are considered for computational offloading. Alternatives are the four cloud servers located in different regions and six criteria. The criteria (QoS parameters) considered are provided in Table 1. AHP method is used for assigning weights for each criterion [26]-[27]. MCDA methods TOPSIS, PROMETHEE II and MOORA are used for selecting the optimal cloud server among a class of cloud servers. The experimental setup is as depicted in Table 2.

Table 1. List of QoS parameters and their description

QoS Attribute	Description
Response Time	Latency in sending the request from mobile device to cloud servers and getting the response from cloud server to mobile device excluding the computation time.
Speed	Time taken by the cloud server in executing the given task.
Proximity	Is the distance measured in kilometers from user location to the cloud servers.
Availability	Signifies availability of virtual machine resources. The server is assumed to be up and running all the time.
Cost per hour	The price of virtual machine per hour. Cost of the servers varies based on the performance and location.
Security	Security settings depend on the cloud service providers.

Table 2. Device specifications

	Mobile Device	Cloud Server1	Cloud Server2	Cloud Server3	Cloud Server4
Model	Sony Xperia M C1904	Amazon EC2 instance t2.medium Asia Mumbai	Amazon EC2 instance t2.medium Sydney	Amazon EC2 instance t2.medium Paris	Amazon EC2 instance t2.medium North Virginia
CPU	Octa-Core 1.6 GHz	2 vCPUs, 2.3 GHz	2 vCPUs, 2.3 GHz	2 vCPUs, 2.3 GHz	2 vCPUs, 2.3 GHz
RAM	3 GB	4 GiB	4 GiB	4 GiB	4 GiB

A mobile app was developed for finding the computation time and communication time taken on each cloud server. Quick sort algorithm was considered as the computationally intensive task to be executed on the cloud servers. The input size of the array was varied from 1 lakh to 5 lakh in steps of 1 lakh. On receiving the unsorted array from the mobile device, the execution of the algorithm happens on the cloud server to sort the array in ascending order and the resultant sorted array was pushed from remote server to the mobile device.

The communication time (response time) taken for sending the unsorted array from mobile device to cloud server and getting the response from cloud server was calculated. The computation time (speed) taken for executing the sorting algorithm on cloud server was calculated. For each input size the experiment was repeated 15 times and average response time and computation time was measured. The experiment was conducted on four cloud servers. The overall average of response time and computation time obtained on each cloud server was considered as the input parameter for the criteria in choosing the optimal cloud server. The criteria value for different alternatives are as shown in Table 3.

The communication time varies based on the location of the server. The user location considered was Bangalore and distance from the user location to the server location was taken as input parameter for the proximity criteria. The cost criterion is the virtual machine cost per hour in dollars for using Amazon web services. The availability and security were assumed to be good for all cloud servers and excellent for cloud server located in Mumbai region.

Table 4 provides the criteria weights obtained using AHP. The consistency ratio CR is 0.055 which is less than 0.1 which is the standard check point in AHP. Hence the weights obtained are consistent. The importance of criteria is ranked in the order response time>speed>proximity>availability>security>cost. The criteria weights obtained by AHP is used by TOPSIS, PROMETHEE-II and MOORA method to rank the cloud servers.

Table 3. Criteria values assigned for different alternatives

Alternatives		Criteria					
Server	Location	Speed	Response Time	Proximity	Cost	Availability	Security
Cloud 1	Mumbai	3.64	19.1	842	0.0496	5	5
Cloud 2	Paris	3.74	21.43	7833	0.0528	4	4
Cloud 3	Sydney	3.75	22.56	9458	0.0588	4	4
Cloud 4	North Virginia	3.85	29.19	14001	0.0464	4	4

Table 4. Criteria weights obtained from AHP

Criteria	Weights
Response time	0.34
Speed	0.27
Proximity	0.22
Availability	0.1
Security	0.04
Cost	0.02

2.1. TOPSIS

Step 1: Normalize the decision matrix, row of matrix represents the alternatives and column represents the criteria.

$$r_{ij} = \frac{X_{ij}}{\sum_{i=1}^{n} X_{ij}^2} \tag{1}$$

Step 2: Normalize the weight matrix, w_j signifies the weight of each criterion.

$$V_{ij} = r_{ij} \times w_j \tag{2}$$

Step 3: Positive ideal solution $V_j^+ = \max\{v_{1j},\ldots v_{nj}\}$ and $V_j^- = \min\{v_{1j},\ldots v_{nj}\}$ for beneficial criteria and $V_j^+ = \min\{v_{1j},\ldots v_{nj}\}$ and $V_j^- = \max\{v_{1j},\ldots v_{nj}\}$ for non-beneficial criteria.

Step 4: Evaluate the alternative distance from V_j^+ and V_j^-.

$$A_i^+ = \left[\sum_{j=1}^{m} \left(V_{ij} - V_j^+\right)^2\right]^{0.5} \tag{3}$$

$$A_i^- = \left[\sum_{j=1}^{m} \left(V_{ij} - V_j^-\right)^2\right]^{0.5} \tag{4}$$

Step 5: Evaluate the performance score of each alternative.

$$P_{i=}\frac{A_i^-}{A_i^+ - A_j^-} \tag{5}$$

Step 6: Performance score is arranged from largest to smallest and the rank is assigned for each alternative. The alternative with highest performance score will be assigned with rank 1 followed by other alternatives [28].

2.2. PROMETHEE II

Step 1: Normalize the decision matrix for beneficial and nonbeneficial criteria as given in (6) and (7).

$$A_{ij} = \left[X_{ij} - \min(X_{ij})\right] / \left[\max(X_{ij}) - \min(X_{ij})\right] \tag{6}$$

$$A_{ij} = \left[\max(X_{ij}) - X_{ij}\right] / \left[\max(X_{ij}) - \min(X_{ij})\right] \tag{7}$$

Step 2: Calculate the variation in criteria values between different pairwise alternatives.

Step 3: Evaluate preference function which represents the difference between the evaluations with respect to alternative i and i` on each criterion as given in (8) and (9).

$$PF_j(i, i') = 0 \quad \text{if } A_{ij} \leq A_{i'j} \tag{8}$$

$$PF_j(i, i') = \left(A_{ij} - A_{i'j}\right) \quad \text{if } A_{ij} > A_{i'j} \tag{9}$$

Step 4: Calculate aggregated preference function. $\pi(i, i')$ indicates the degree of i preferred to i` over all criteria.

$$\pi(i, i') = \frac{\left[\sum_{i=1}^{m} w_j * PF_j(i,i')\right]}{\sum_{j=1}^{m} w_j} \tag{10}$$

Step 5: Find the leaving and entering outranking flows. The leaving or positive outranking flow signifies how an alternative is outranking the rest of the alternatives. The higher the leaving outranking the better the alternative. The entering or negative outranking flow signifies how an alternative is outranked by all other alternatives. The lower the entering outranking the better the alternative. Alternative with a greater value of positive outranking and lesser value of negative outranking is the best alternative.

$$\emptyset^+(i) = \frac{1}{n-1}\sum_{i'=1}^{n} \pi(i, i') \tag{11}$$

$$\emptyset^{-}(\mathrm{i}) = \frac{1}{\mathrm{n}-1}\sum_{\mathrm{i}'=1}^{\mathrm{n}} \pi\,(\mathrm{i}', \mathrm{i}) \qquad (12)$$

Step 6: Each alternatives net outranking flow is calculated.

$$\emptyset(\mathrm{i}) = \emptyset^{+}(\mathrm{i}) - \emptyset^{-}(\mathrm{i}) \qquad (13)$$

Step 7: The net outranking flow is arranged from largest to smallest. Alternative with largest value is the optimal solution and will be assigned with rank 1 followed by other alternatives [29], [30].

2.3. MOORA

Step 1: Normalize the decision matrix. X_{ij}^{*} is the normalized performance of i^{th} alternative on j^{th} criteria.

$$x_{ij}{}^{*} = x_{ij} \Big/ \left[\sum_{i=1}^{m} x_{ij}{}^{2}\right]^{\frac{1}{2}} \qquad (j = 1,2,3 \ldots\ldots n) \qquad (14)$$

Step 2: Normalized data is multiplied with weight criteria for all alternative.

Step 3: Estimation of assessment values is obtained using the (15) where summation of beneficial and nonbeneficial attributes are calculated. Next the difference between the summation of beneficial and non-beneficial is calculated. g will represent the number of columns until where attributes are beneficial, and n represents the total number of columns.

$$y_i = \sum_{j=1}^{g} w_j x_{ij}{}^{*} - \sum_{j=g+1}^{n} w_j x_{ij}{}^{*} \qquad (j = 1,2,3 \ldots\ldots n) \qquad (15)$$

Step 4: Assessment values is arranged from largest to smallest. Alternative with highest value is the optimal solution and will be assigned with rank 1 followed by other alternatives [31].

3. RESULTS AND DISCUSSION

Case 1: Selection of optimal cloud server using TOPSIS

The results obtained using TOPSIS to rank the optimal cloud is as represented in Table 5. The table provides the complete overview of positive ideal solution (Ai^{+}), negative ideal solution (Ai^{-}), performance score(P_i) and ranking of each alternative. Based on ranking cloud 1 is the optimal cloud server.

Table 5. Ranking of cloud server using TOPSIS

Alternatives		Ai^{+}	Ai^{-}	Pi	Rank
Server	Location				
Cloud 1	Mumbai	0.000614	0.172394	0.996449	1
Cloud 2	Paris	0.085246	0.0922005	0.519595	2
Cloud 3	Sydney	0.105602	0.072199	0.406066	3
Cloud 4	North Virginia	0.172385	0.002379	0.013617	4

Case 2: Selection of optimal cloud server using PROMETHEE-II

The results obtained using PROMETHEE II to rank the optimal cloud is as represented in Table 6. The table provides the complete overview of the leaving, entering and net outranking flows and ranking of each cloud server. Based on the ranking, cloud 1 is the optimal cloud server.

Table 6. Ranking of cloud server using PROMETHEE-II

Alternatives		$\emptyset^{+}$	$\emptyset^{-}$	$\emptyset$	Rank
Server	Location				
Cloud 1	Mumbai	0.6653	0.0017	0.6636	1
Cloud 2	Paris	0.1979	0.1598	0.0381	2
Cloud 3	Sydney	0.1426	0.2216	-0.0789	3
Cloud 4	North Virginia	0.0118	0.6347	-0.6228	4

Case 3: Selection of optimal cloud server using MOORA

The results obtained using MOORA to rank the optimal cloud is as represented in Table 7. The table provides the complete overview of the normalized data multiplied with the weight criteria for all alternative and the assessment value (Y_i). Based on the ranking, it is seen that cloud 1 is the optimal cloud server.

Table 7. Ranking of cloud server using MOORA

Alternatives		W_j x X_{ij}*						Y_i	Rank
Server	Location								
Cloud 1	Mumbai	0.1312	0.1389	0.0099	0.0095	0.0585	0.0234	-0.20764	1
Cloud 2	Paris	0.1348	0.1559	0.0924	0.0101	0.0468	0.0187	-0.32769	2
Cloud 3	Sydney	0.1352	0.1641	0.1116	0.0113	0.0468	0.0187	-0.35661	3
Cloud 4	North Virginia	0.1388	0.2123	0.1652	0.0089	0.0468	0.0187	-0.45966	4

3.1. Sensitivity analysis

Sensitivity analysis is performed to evaluate the robustness of the proposed work and to check the consistency of the obtained results. Sensitivity analysis is performed by generating different situations. Situations are generated by exchanging the weights of one criterion with another criterion [23]. The overall ranking of alternatives is analyzed based on generated situations. If the ranking order changes when the criteria weights are interchanged, then we can conclude that the results are sensitive otherwise it is robust. The proposed work analyses the impact of criteria weight by exchanging the weights and performing 15 runs for three different cases.

Case 1: AHP and TOPSIS

Table 8 gives the results of the sensitivity analysis performed by interchanging criteria weights and calculating the performance index for each run to rank the cloud server. Interchange of criteria weights is denoted by the definition attribute in Table 8. For example, C1-C2 indicates the weight of criteria C1 and C2 has been exchanged. Out of 15 experiments conducted by interchanging the weights it is observed that cloud server 1 is the optimal cloud server. Figure 1 gives the ranking of the cloud servers after performing sensitivity analysis and it is observed that cloud server 1 is the optimal cloud server even after exchange of weights. Hence the cloud service selection model using TOPSIS is robust and not sensitive to criteria weights.

Table 8. Sensitivity analysis using TOPSIS

Definition	Cloud 1	Cloud 2	Cloud 3	Cloud 4
C1-C2	0.996	0.502	0.387	0.0136
C1-C3	0.997	0.505	0.389	0.0111
C1-C4	0.954	0.518	0.395	0.153
C1-C5	0.996	0.505	0.397	0.013
C1-C6	0.996	0.503	0.395	0.013
C2-C3	0.997	0.479	0.358	0.009
C2-C4	0.938	0.466	0.328	0.2009
C2-C5	0.996	0.448	0.336	0.014
C2-C6	0.996	0.441	0.329	0.0142
C3-C4	0.92	0.687	0.553	0.25
C3-C5	0.994	0.572	0.478	0.0214
C3-C6	0.992	0.614	0.537	0.0267
C4-C5	0.982	0.521	0.406	0.0628
C4-C6	0.992	0.519	0.406	0.026
C5-C6	0.996	0.519	0.406	0.013

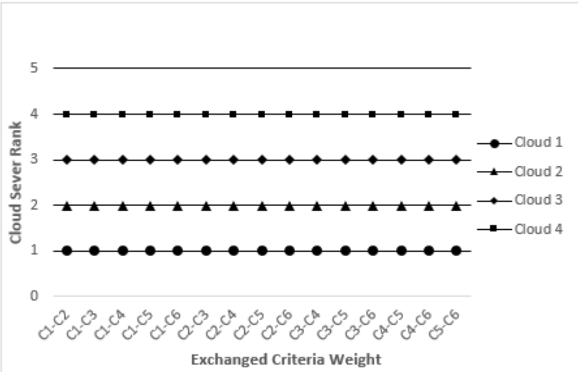

Figure 1. Rank of cloud servers using TOPSIS

Case 2: AHP and PROMETHEE II

Table 9 gives the results of the sensitivity analysis performed by interchanging the criteria weights and calculating the net outranking flow for each run to rank the cloud server. Out of 15 experiments conducted by interchanging the weights, it is observed that cloud server 1 is the optimal cloud server. Figure 2 gives the ranking of the cloud servers after performing sensitivity analysis and it is observed that cloud server 1 is the optimal cloud server even after exchange of weights. Deviation in ranking is noticed between cloud server 3 and cloud server 4 when the weights of criteria 2 and 4 are exchanged but overall experiment results are the same.

Table 9. Sensitivity analysis using PROMETHEE II

Definition	Cloud 1	Cloud 2	Cloud 3	Cloud 4
C1-C2	0.667	0.0252	-0.0859	-0.6124
C1-C3	0.666	0.376	-0.0845	-0.6197
C1-C4	0.558	0.006	-0.2565	-0.3083
C1-C5	0.7203	-0.0239	-0.1302	-0.5662
C1-C6	0.7403	-0.0458	-0.1483	-0.5462
C2-C3	0.6881	0.0146	-0.1043	-0.5983
C2-C4	0.5749	-0.0622	-0.3379	-0.1748
C2-C5	0.7777	-0.0939	-0.1751	-0.5087
C2-C6	0.8062	-0.1269	-0.1991	-0.4802
C3-C4	0.5674	0.0147	-0.1984	-0.3836
C3-C5	0.6962	-0.0043	-0.1016	-0.5903
C3-C6	0.7125	-0.0255	-0.1129	-0.574
C4-C5	0.6034	0.057	-0.1116	-0.5488
C4-C6	0.6486	0.0429	-0.0871	-0.6043
C5-C6	0.6636	0.0381	-0.0789	-0.6228

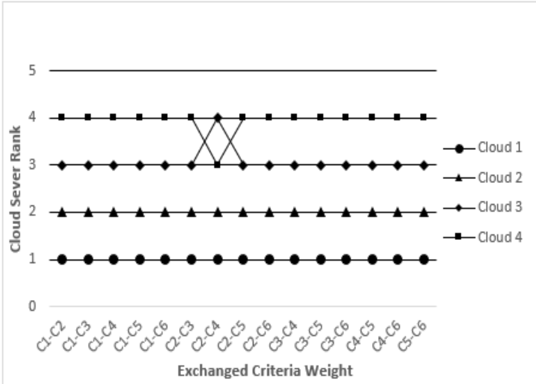

Figure 2. Rank of cloud servers using PROMETHEE II

Case 3: AHP and MOORA

Table 10 gives the results of the sensitivity analysis performed by interchanging the criteria weights and calculating the assessment values for each run to rank the cloud server. Out of 15 experiments conducted by interchanging the weights, it is observed that cloud server 1 is the optimal cloud server. Figure 3 gives the ranking of the cloud servers after performing sensitivity analysis and it is observed that cloud server 1 is the optimal cloud server even after exchange of weights. Hence the cloud service selection model using MOORA is robust and not sensitive to criteria weights.

Table 10. Sensitivity analysis using MOORA

Definition	Cloud 1	Cloud 2	Cloud 3	Cloud 4
C1-C2	-0.213	-0.33	-0.357	-0.451
C1-C3	-0.185	-0.323	-0.356	-0.471
C1-C4	-0.205	-0.329	-0.371	-0.442
C1-C5	-0.025	-0.163	-0.191	-0.29
C1-C6	0.038	-0.105	-0.153	-0.233
C2-C3	-0.164	-0.323	-0.35	-0.474
C2-C4	-0.229	-0.343	-0.3818	-0.4026
C2-C5	0.0308	-0.105	-0.128	-0.197
C2-C6	0.09	-0.049	-0.071	-0.131
C3-C4	-0.29	-0.345	-0.367	-0.398
C3-C5	-0.132	-0.221	-0.239	-0.3133
C3-C6	-0.094	-0.167	-0.18	-0.24
C4-C5	-0.292	-0.405	-0.438	-0.532
C4-C6	-0.228	-0.347	-0.377	-0.477
C5-C6	-0.207	-0.327	-0.356	-0.459

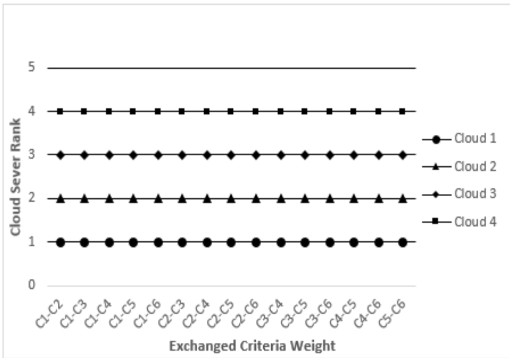

Figure 3. Rank of cloud servers using MOORA

In mobile environment, cloud service selection is not explored to the fullest. In the proposed work, four real time cloud servers located at different regions with real time criteria values are considered. TOPSIS, PROMETHEE II and MOORA were proved to be viable solutions in finding optimal cloud server. Results of sensitivity analysis prove that the proposed decision models for selecting the optimal cloud server is robust and interchanging the criteria weights doesn’t have much impact on the decision provided.

3.2. Execution time comparison

Figure 4 depicts the execution time taken by each MCDM method to find the optimal cloud server. To examine which method is faster, the number alternatives were varied from four to twenty in steps of four. Each run was performed 15 times and average time was taken for each alternative. The results indicate that the two new approaches proposed for cloud path selection in mobile cloud computing MOORA and PROMETHEE II are faster compared to TOPSIS [25]. Real-world dataset was used to perform the experiment and the results proves the efficiency of the proposed methodology. Sensitivity analysis further proves the correctness of the proposed methodology.

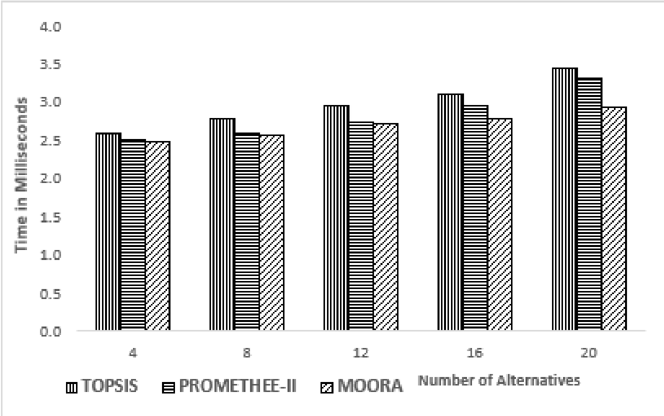

Figure 4. Time analysis of TOPSIS, PROMETHEE-II and MOORA

4. CONCLUSION

In the proposed work, multicriteria decision methods for selecting the optimal cloud server from a class of cloud servers offering similar services are analyzed in a mobile cloud computing environment. The proposed model is validated by using real time dataset values for QoS parameters by executing the task on cloud server and communicating with mobile device. Four real time cloud servers located at different regions, six QoS parameters are considered for the work and three different MCDM methods are used. All three methods emerge as viable solutions in selecting the optimal cloud server. The two new approaches MOORA and PROMETHEE II proposed in the work are faster compared to the existing approach using TOPSIS. Sensitivity analysis proved that the proposed method is robust irrespective of change in criteria weights.

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