MADM-based Network Selection in Heterogeneous Wireless Networks: A Simulation Study

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***Abstract*—Recently, network selection in heterogeneous wireless networks has been widely studied by using various mathematical models, in which MADM is one of the most popular. However, this model still has lots of existing issues in many scenarios, and there is lack of study on how to solve these issues in the scope of MADM-based network selection. Based on our previous survey, we firstly provide in this paper extensive simulations to demonstrate this model's feasibility in various scenarios. Meanwhile, we identify several important issues that have not been well solved in the current literature, such as the requirement of efficient weighting method, the usage of VHO properties, the tradeoff for handing-over to the new best network, and the immoderate load balancing compromising importance of other criteria. Combining with our studies on these issues, we finally propose a four-step integrated strategy for MADM-based network selection.**

***Index Terms*—network selection; heterogeneous wireless networks (HWNs); multiple attribute decision making (MADM); always best connected (ABC)**

I. Introduction

In the context of the present trend towards ubiquity of networks and global mobility of services, we see that network access is provided by a large diversity of technologies with coverage overlaps. In this heterogeneous wireless network (HWN) environment, the previous always connected concept becomes *always best connected* (ABC) which requires dynamic selection of the best network and access technology when multiple options are available simultaneously [1].

In the near future, the HWN environment could contain multiple networks, such as universal mobile telecommunications system (UMTS), world-wide interoperability for microwave access (WiMAX), wireless local area network (WLAN) and Bluetooth. These networks have various attributes [2]–[5], which are either static, e.g. monetary cost, bandwidth, security level, bit error rate, jitter, power consumption, handover latency, etc.; or dynamic, e.g. traffic load, signal strength, handover signaling cost, etc. Besides, mobile terminals (MTs) have various properties, customers have various preferences and applications have various QoS requirements. Therefore, it is quite difficult to define the *best network* in the network selection issue because no network is better than others in all aspects. In order to always select a reasonable network, it is necessary to take a large number of factors into consideration simultaneously.

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Among all the factors, network attributes compose a large category, which are generally used as decision criteria to characterize different aspects of a network's capabilities. Since these criteria have different measurement units, utilities and inexactness, their values need to be adjusted before combining together. Usually, besides normalization, utility theory and fuzzy logic can also be used for these adjustments [6], [13]. Meanwhile, in order to combine multiple criteria together, weights are required to represent their relative importance, so certain weighting method, e.g. analytical hierarchy process (AHP) [5], should be used to evaluate their weights.

After all the criteria are adjusted and their weights are calculated, they can be combined together as a total cost or utility based on certain multiple attribute decision making (MADM) algorithm [4]–[11], e.g. simple additive weighting (SAW), multiplicative exponential weighting (MEW), technique for order preference by similarity to ideal solution (TOPSIS), grey relational analysis (GRA), elimination and choice translating reality (ELECTRE), etc. In the end, a rank of these networks is obtained and the first one in the rank is chosen as the best network.

Based on recent overviews and performance comparisons [10]–[12], a large number of proposals on network selection have the above accordant understanding on combining various criteria to solve the network selection issue, summarized as Fig. 1. Meanwhile, some proposals (e.g. gaming model [14], knapsack model [15], Markov decision process model [16], etc.) try to solve the network selection issue in different ways. Among all the proposals, MADM is one of the most popular model for the network selection issue, but there is lack of extensive study to demonstrate whether this model works well in various scenarios and whether there is still unsolved problem in the scope of MADM-based network selection.

Therefore, in this paper, we do extensive simulations for various scenarios to demonstrate the MADM model's feasibility for the network selection issue in Section II; based on our simulations, we then find out several unsolved issues of MADM-based network selection; finally, we propose a four-step integrated strategy for MADM-based network selection to solve these issues.

II. MADM Network Ranking Algorithms

As shown in Fig. 1, network ranking module integrates all the information coming from weighting and adjusting

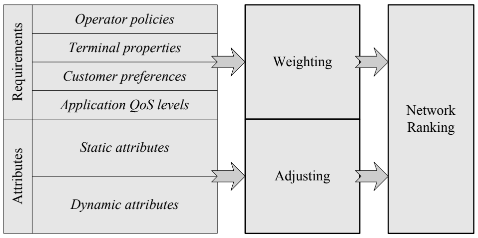


Fig. 1. MADM-based network selection.

TABLE I
HIGH WEIGHTS DUE TO SUBJECTIVE REQUIREMENTS

Subjective requirements		Criteria with high weights
low price	→	monetary cost
high speed	→	mobility-related criteria
poor power condition	→	power consumption
conversational applications	→	jitter
streaming applications	→	bandwidth and jitter
interactive applications	→	security level
background applications	→	BER and security level

modules, and obtains a rank of all the networks. Up to now, MADM algorithms [4]–[11] that have been used for network ranking include SAW, MEW, GRA, TOPSIS, ELECTRE, etc. The first four algorithms rank networks based on their coefficients (such as total costs or total utilities) calculated by combining adjusted values of all the criteria, while the last algorithm use pair-wise comparisons among all the networks, which is a totally different procedure.

In **SAW** and **MEW**, the coefficients are calculated separately by additive and multiplicative operations:

$$C_{SAW} = \sum_{j=1}^{M} \omega_j v_{i,j}, \text{and} \tag{1}$$

$$C_{MEW} = \prod_{j=1}^{M} v_{i,j}^{\omega_j}, \tag{2}$$

where ω_j represents the weight of the jth criterion, $v_{i,j}$ represents the adjusted value of the jth criterion of the ith network.

Equation (2) can be modified as

$$C^*_{MEW} = ln(C_{MEW}) = \sum_{j=1}^{M} \omega_j ln(v_{i,j}). \tag{3}$$

Considering the characteristic of the natural logarithm, the criterion whose cost being close to 0 has large impact on the total cost than others. For example, Bluetooth is more often selected by MEW than by other algorithms due to its low monetary and power costs, as shown in our later simulations.

In **GRA**, gray rational coefficient (GRC) is used as the coefficient to describe the similarity between each candidate network and the best reference network (an ideal network formed by choosing the best value of each criterion), which is calculated as

$$C_{GRA} = \frac{1}{\sum_{j=1}^{M} \omega_j |v_{i,j} - R_j| + 1}, \tag{4}$$

where R_j represents the ideal value of the jth criterion. If we firstly inverse all the 'larger-the-better' criteria into 'smaller-the-better' ones, the operation of calculating the absolute value in the above equation is eliminated. Thus, we can see that GRA should have similar performance with SAW.

In **TOPSIS**, the best network is the one closest to the best reference network $R_{b,j}$ and farthest from the worst reference network $R_{w,j}$. The coefficient is calculated as

$$C_{TOPSIS} = \frac{D_{\omega,i}}{D_{b,i} + D_{\omega,i}}, \tag{5}$$

where $D_{\omega,i/b,j} = \sqrt{\sum_{j=1}^{M} \omega_j^2 (v_{i,j} - R_{\omega,j/b,j})^2}$.

ELECTRE is more complicated than the above four algorithms. It firstly uses pair-wise comparisons of networks to obtain a $CSet(i,j)$ indicating the criteria of network i better than network j and a $DSet(i,j)$ indicating the criteria of network i worse than network j. Then, two pair-wise comparison matrices (called concordance and discordance) are formed. The element (i,j) of concordance is calculated as a sum of weights of criteria in the $CSet(i,j)$; while element (i,j) of discordance is calculated as a sum of the differences of criteria in the $DSet(i,j)$. In the end, elements of the two matrices are compared separately with $C_{threshold}$ and $D_{threshold}$ to indicate if one network is preferred to another or not.

III. SIMULATION RESULTS

A. Configuration of network selection simulator

To do extensive simulations, we establish, in this section, a network selection simulator which is configured as follows:

Criteria: numerous criteria are used together, e.g. monetary cost, bandwidth, power consumption, security level, traffic load, signal strength, bit error rate, jitter, etc.

Requirements: two terminal properties (i.e. power condition and velocity) and four QoS levels (i.e. conversational, streaming, interactive and background) are considered. Besides, the customer prefers low monetary cost and good signal strength; while the operator wants load balancing to avoid congestion in the best network.

Networks: the heterogeneous environment is composed of WPAN, WLAN, WMAN and WWAN.

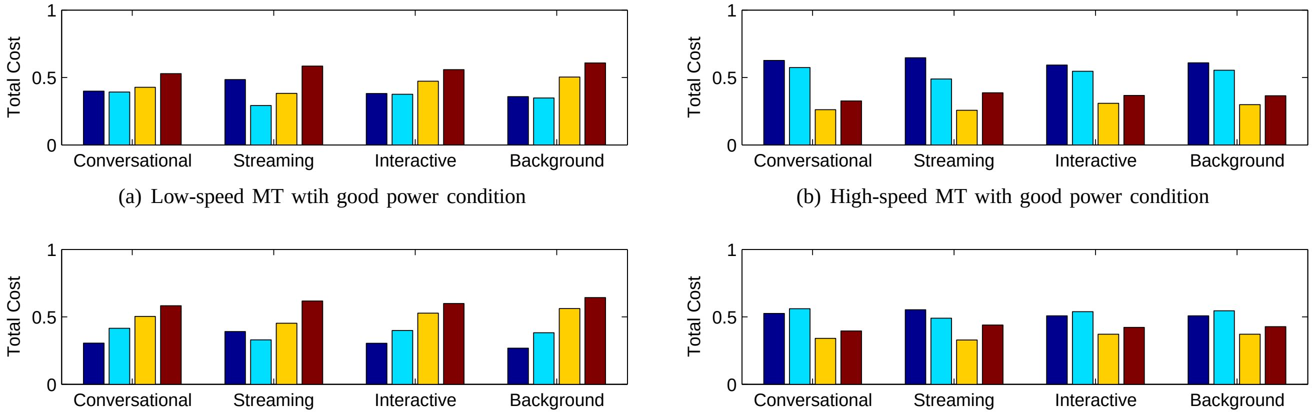
Weighting: weights of different criteria are manually calculated by AHP for various scenarios.

Adjusting: all the attribute values are normalized and further adjusted through sigmoidal utility function.

Network ranking: five MADM algorithms, as explained in Section II, are considered.

B. Effects of Terminal-side requirements in MADM-based network selection

In this sub-section, we study the impacts of terminal properties and application QoS requirements on network selection



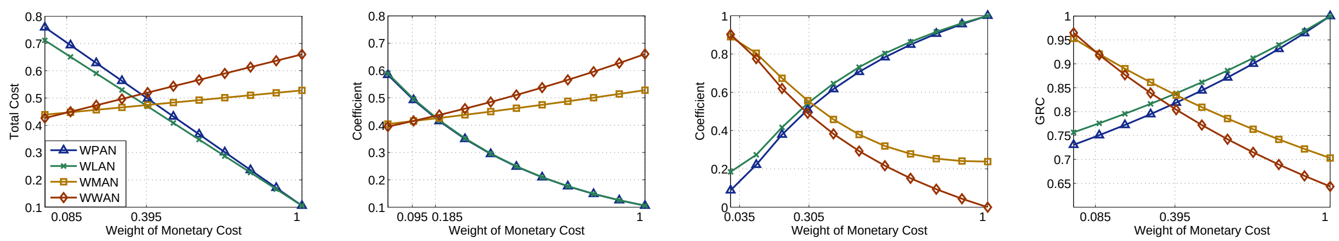
(a) Low-speed MT wtih good power condition

(b) High-speed MT with good power condition

(c) Low-speed MT with poor power condition

(d) High-speed MT with poor power condition

Fig. 2. Total cost for different terminal properties and applications (from left to right: WPAN, WLAN, WMAN and WWAN).



(a) SAW

(b) MEW

(c) TOPSIS

(d) GRA

Fig. 3. Coefficients' changes with respect to certain criterion's weight.

results. Weights affected by various requirements are listed in TABLE I, where left-hand requirements can result in high weights of right-hand criteria.

Total costs of four networks in these scenarios are shown in Fig. 2. When terminal properties and applications change, high weights are used for corresponding criteria, hence total costs of networks change and different networks are selected in different scenarios.

C. Coefficients of various MADM algorithms

In this sub-section, we simulate four MADM algorithms (SAW, MEW, TOPSIS and GRA), and show their coefficients' changes with respect to certain criterion's weight, as shown in Fig. 3. ELECTRE is an algorithm that uses pair-wise comparisons between different networks, so it is not considered in this simulation.

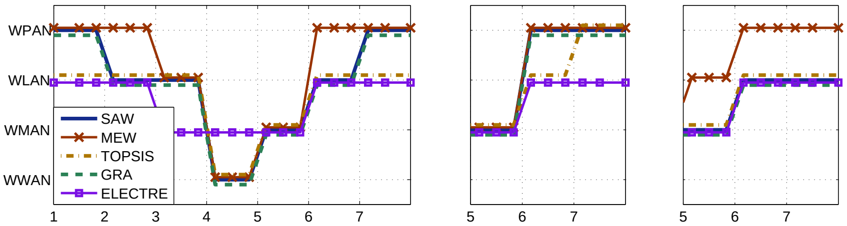
For SAW and MEW, the best network corresponds to the one with minimum coefficient; while for TOPSIS and GRA, the best network corresponds to the one with maximum coefficient.

We can see from Fig. 3 that, some networks have similar performance, while some others are totally different. In most cases, several high-performed networks' coefficients are close, which means there is little difference by selecting any of them. This feature provides us the following information: 1) VHO tradeoff is important, otherwise a customer might handover frequently between two networks with similar performance; 2) load balancing is important, otherwise all the customers in an area might select the same network and ignore other networks with similar high performance; 3) due to normalization and sigmoidal utility function, some networks' coefficients increase, while some decrease. According to our simulations, this feature fits for most of the criteria (e.g. mobility-related criteria in [18]), so it is easy to distinguish between good and poor networks and classify them into different groups.

D. Selection results of various MADM algorithms

In this sub-section, we consider two customers using separately single-homed MT (SMT) and multi-homed MT (MMT) move together within a heterogeneous environment consisting of four networks. SMT can only connect to the Internet through one interface at one time, so the selection of its best network should consider simultaneously all the applications together. By contrast, MMT is capable of connecting through multiple interfaces, so different applications might select different networks if necessary. As shown in Fig. 6, a consecutive series of scenarios are designed for simulation, which is further explained in TABLE II.

When there is only a single application (such as App1 in scenarios 1, 2, 3 or 4), the two MTs could use the same group of weights; by contrast, when there are multiple applications (such as App1 and App2 in scenarios 5, 6 or 7), the multi-homed MT could use different interfaces for different applications, so two groups of weights are used. Fig. 4 shows



(a) SMT (b) App1 of MMT (c) App2 of MMT

Fig. 4. MADM algorithms' selection results for a series of scenarios.

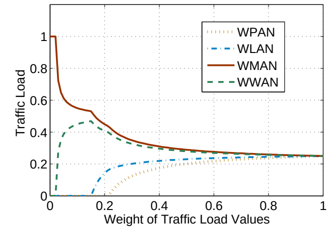


Fig. 5. Load balancing feature.

TABLE II
A SERIES OF SCENARIOS

N.	Location	Changes of Apps	Changes of Networks & MTs
1)	office	+ WWW	–
2)	meeting room	–	WPAN High-traffic
3)	coffee house	–	WLAN NOT Totally Free
4)	taxi	–	WPAN Low-traffic
5)	taxi	+ Video Conf.	–
6)	auditorium	–	WLAN Free
7)	auditorium	–	Battery Low

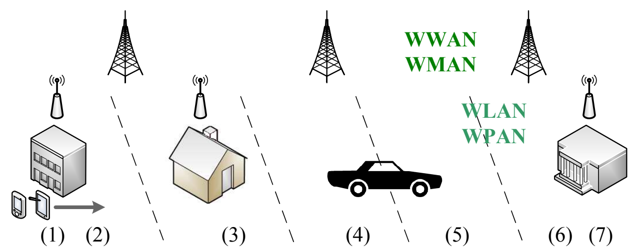


Fig. 6. A series of scenarios.

separately the two MTs selection results, which are the same in the first four scenarios and different in others.

E. Load balancing by MADM-based network selection

By considering traffic load as a dynamic criterion in the network ranking module, it is possible to achieve load balancing. In this sub-section, load balancing feature in MADM-based network selection schemes is studied. In this simulation, we assume that 1000 sessions of an MT with high speed and good power condition arrive one by one, and each of them occupies 0.1% of the selected network's resource. As shown in Fig. 5, when the weight of traffic load is small, WMAN is selected as the best network. Along with the increase of the weight, this networks' traffic load is considered in the network ranking procedure, so other networks are gradually selected by. Finally, when the weight of traffic load is relatively large, each network takes approximately 1/4 of the whole traffic.

IV. DISCUSSIONS AND A PROPOSED STRATEGY

A. Important observations and issues

Based on the simulations in Section III, we briefly summarize our most important observations as follows:

1) it is feasible to use terminal-side and operator-side requirements to impact the weights of different criteria, but the pair-wise comparison matrix in AHP changes dynamically and frequently for different scenarios;

2) it is common to have several networks with performance close to the best one, so load balancing and VHO tradeoff are both important. Moreover, it might be a good idea to divide all the networks into groups;

3) MADM algorithms may have different coefficients and selection results, but all of them can generally select reasonable networks in various scenarios;

4) using traffic load as a criterion in the network ranking algorithm is a simple method, but achieves load balancing very well among the networks with similar performance.

Then, we find several existing issues in the scope of the MADM-based network selection:

Weighting method: it is inconvenient to manually evaluate weights for different scenarios based on pair-wise comparison matrices by AHP, so novel weighting method is required to efficiently and quickly evaluate weights for different scenarios;

Mobility-related factors: VHO properties depend on the priorities of networks (i.e. permutation) and cannot be easily used as criteria for network ranking, so further study on how to combine these criteria with other network attributes is required;

VHO tradeoff: after a better network is found by the MADM-based network ranking algorithm, the MT might not want to handover to it in lots of scenarios. For example, the better network might be only a little bit better than the current network, the better network might disappear rapidly, a much better network might appear in a few time, etc. Therefore, a tradeoff is required before executing VHO.

Load balancing: using traffic load as a criterion is possible to balance the load, but weight on this criterion compromises other criteria's importance, even when load balancing is not required.

B. An MADM-based network selection strategy

In this sub-section, we propose an integrated strategy for MADM-based network selection, based on our study of the above issues. The strategy contains four steps: the first step is to monitor the triggers and to gather the required information [3]; the second step is the preparation before combining all the criteria, including weighting and adjusting of criteria; the third step is to combine multiple criteria based on MADM algorithms; and the last step is an VHO tradeoff algorithm. In our strategy, the following parts require further explanation:

Efficient subjective weighting: there are two types of weights, subjective and objective. It is not sufficient to represent the importance of attributes by using only one of the two types, so we suggest combine subjective and objective weights together. In the proposed strategy, subjective information (e.g. terminal properties, customer preferences, application QoS levels and operator policies) is used for calculating subjective weights, while values of network attributes are used for calculating objective weights. However, it is not efficient to use AHP for subjective weighting, so we suggest a trigger-based subjective weighting method here. As we know, any obvious change of subjective information can trigger the selection scheme because this change will lead to a change of subjective weights, hence a change of different networks' total costs. Therefore, the relationship between the change of subjective information and the change of subjective weights is the key point in the weighting procedure. In our network selection strategy, we use a mapping pot to store the effects of triggers on the change of subjective weights. Since this mapping pot are generally fixed, the calculation of subjective weights becomes much easier and faster than AHP. More important, this trigger-based method is totally automatic, which does not need any manual pair-wise comparison between criteria [17].

Mobility-based network selection: VHO properties should be considered for network ranking; otherwise, the selection scheme might select a network with small cells, which leads to frequent VHOs and severely disturbs real-time applications. Since VHOs correspond to the permutation of networks, the selection of a best network becomes the selection of a permutation when VHO is taken into account. However, when there are n networks, the number of permutations will be the factorial of n, which leads to an obvious time complexity problem. Therefore, we propose a two-step permutation-based network selection scheme (*Besnet* + *Besper*) to easily get the best network and the best permutation, i.e. the MADM step in Fig. 7. In Besnet, we firstly get the best network by permutation-based pair-wise comparisons among all the networks, and VHO is performed immediately. Then, we find the best permutation as the one with minimum total cost in Besper, which takes a relative long time. In this way, the time complexity of Besper does not increase VHO latency, hence not a problem any more [18], [19]. Moreover, we classify all the networks into several groups at the end of the adjusting module, in order to further decrease the time cost of Besper. This grouping operation is based on adjusted values of several most important criteria, e.g. cell radius, bandwidth, monetary cost, etc., which is reasonable according to our simulations.

VHO tradeoff scheme: based on VHO properties and the rank provided by the network ranking module, a final decision is made in the last step of our strategy. In this procedure, the current network is compared one by one with the networks with higher performance. Once a network passes the tradeoff, the comparison procedure will be stopped and VHO will be performed. By contrast, if no network can pass the tradeoff, the current network will be still used. The tradeoff should consider the two networks' relative difference and the better network's predictive residential time.

Load balancing method: seen from our simulation results, it is feasible to use traffic load values as a criterion in the ranking algorithm for load balancing, and it works well for networks with similar performance. However, for networks with quite different performance, this method has an obvious problem. Considering two networks with both low but totally different traffic loads, normalization process will ignore the two networks' actual low traffic loads but retain only the relative large difference, which leads to immoderate load balancing between the two networks and compromises the importance of other criteria. To solve this problem, we suggest not process traffic load values in the same way as other criteria. For example, we could use function $U = a^{v_{TL}-1}$ to calculate the utility, where v_{TL} is the traffic load value and $a > 1$ is an experiential constant. We suggest use a large value for a to avoid the immoderate load balancing problem.

V. Conclusions

We firstly provided in this paper extensive simulations to demonstrate MADM model's feasibility for modeling network selection and its appropriateness for selecting reasonable networks in various scenarios. Meanwhile, we summarized several important observations and identified four existing issues on MADM-based network selection methods that have not been well solved in the current literature, such as the requirement of efficient weighting method, the usage of VHO properties, the tradeoff for handing-over to the new best network, and immoderate load balancing compromising the importance of other criteria. Combining with our studies on these issues, we proposed finally a four-step integrated strategy of MADM-based network selection to solve all the above issues together.

Two topics of MADM-based network selection, we believe, still require further study: the utility function for traffic load values and the tradeoff function, as highlighted in the procedure of the proposed strategy.

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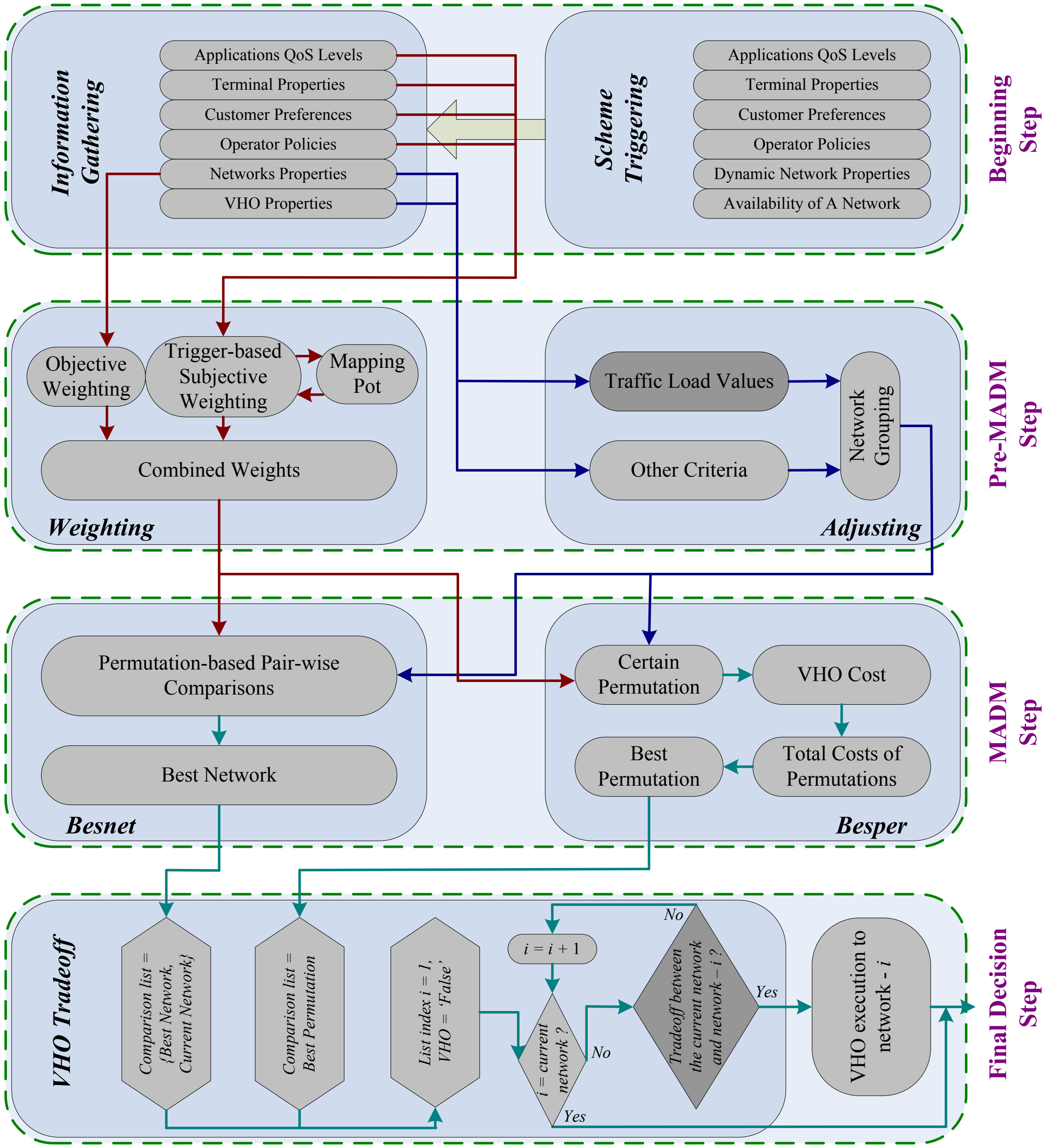

Fig. 7. An integrated strategy for MADM-based network selection.

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