Towards a framework of network selection in heterogeneous wireless networks

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2009C001

juillet 2009

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Towards A Framework of Network Selection in Heterogeneous Wireless Networks

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***Abstract*—In this paper, we firstly provide a brief survey of the network selection issue, including five main components (factors, weighting methods, normalization & fuzzification, network ranking algorithms and load balancing schemes) which can largely influence the selection results. Based on this study, we then propose a framework, which fits for a large number of recent propositions on network selection. The framework employs six groups of factors: terminal properties, customer preferences, application QoS levels, static network properties, dynamic network properties and vertical handover properties. The former three groups indicating terminal-side requirements are used to calculate the weights, while the latter three groups representing network-side criteria are normalized and fuzzificated. Then, the adjusted criterion values and the weights are combined by certain network ranking algorithm, and a final decision is made based on the rank together with vertical handover tradeoff. At the end of this paper, seven specially designed consecutive scenarios are simulated for both single-homed and multi-homed mobile terminals, which shows the framework's feasibility for different situations in a heterogeneous environment.**

Keywords-Network selection, heterogeneous wireless networks (HWNs), always best connected (ABC), multi-criteria decision making (MCDM), multihoming.

I. INTRODUCTION

In the context of the present trend towards ubiquity of networks and global mobility of services, we see that access is provided by a large diversity of technologies with coverage overlaps. The previous concept "always connected" becomes "always best connected (ABC)" which means always connecting to the best network when multiple options are available simultaneously [1] [2]. This requires dynamically selecting the best network and access technology based on the combination of a large number of factors.

Network selection, as one of the most important parts of ABC, is to select the best network among heterogeneous wireless networks (HWNs) to access the Internet based on various factors for a mobile terminal (MT) or a traffic flow of a multi-homed MT [3] [4]. An HWNs environment could contain several of the following networks: universal mobile telecommunications system (UMTS), world-wide interoperability for microwave access (WiMax), wireless local area network (WLAN), Bluetooth, etc.

These networks have different properties: most of which are static, such as monetary cost, bandwidth, power consumption capability, security level, bit error rate, jitter, handover latency, etc. By comparison, some others dynamically change from time to time, e.g. traffic load, signal strength, handover signaling cost, etc. Moreover, MTs have their own properties, customers have different preferences, and applications have different QoS levels [10] – [12]. Therefore, it is quite difficult to define the "best" in the network selection issue, and no network can be better than others on every factor or in all cases. In order to make a more reasonable choice, it's necessary to take more factors into consideration.

To deal with multiple criteria, weights should be used to represent their importance. In the related work, there are only a few methods proposed for weighting the criteria, e.g. analytic hierarchy process (AHP) [3] and entropy [6]. Intuitively, criteria' weights are dependent on the factors and the other modules in network selection schemes.

Up to now, network selection is widely studied and in particular modeled by different kinds of mathematic tools, e.g. multi-criteria decision making (MCDM), fuzzy logic (FL), knapsack, game theory, etc. [7] [8] [9]. These models, together with factors and weighting methods, are main components of the network selection issue, but different models have different functions and fit for different situations. To the best of our knowledge, none of them is proved to be suitable for solving this issue alone. For example, MCDM could be used for network ranking; FL could be used to fuzzificate the factors; while knapsack and game theory are used to achieve load balancing among these wireless networks during the network selection procedure. Therefore, it's quite necessary to categorize these models clearly based on their functions, so that they could be used on the right position of this issue.

The rest of this paper is organized as follows: in section II, state of the arts is briefly presented in five sub-sections corresponding to five components; in section III, we propose a framework and simulate a series of consecutive scenarios to prove its feasibility. At last, this paper is concluded and some important issues in the scope of the proposed framework are suggested in section IV.

II. NETWORK SELECTION COMPONENTS

A. *Factors and categorization*

Factors are the basis of selecting the best network for an MT or a traffic flow of a multi-homed MT. A

This research is funded by France Telecom R & D.

network selection scheme should synthetically consider multiple factors. In fact, there are such a large number of factors which should be considered (not only network-side criteria including static network properties, dynamic network properties and vertical handover (VHO) properties, but also terminal-side requirements including terminal properties, customer preferences and application QoS levels) that to define the “best” network is quite difficult.

In related work, most of the factors mentioned in this section have been used by one or multiple proposals, but there is little specific discussion on why these factors are chosen and why they are used in such ways. As we know, using certain essential factor in a wrong way may result in sub-optimal selection results [18], so we emphasize that the choice and the usage of factors are quite important in the network selection issue. However, since the definition of the “best” network is not fixed, it’s not possible to conclude which network selection scheme is better than others, especially in some ambiguous cases when multiple networks have similar performances. Therefore, in order to use these factors reasonably and effectively, we provide here an analysis and categorization of the factors that, we believe, should be considered in the network selection issue.

As shown in Fig. 1, factors are classified into two groups: network-side criteria and terminal-side requirements. The former group can be further divided into three groups, i.e. static network properties, dynamic network properties and VHO properties; while the latter includes terminal properties, customer preferences and application QoS levels. The network-side criteria are usually adjusted by normalization and fuzzification; while the terminal-side requirements are used to decide the weights of the network-side criteria. Then, the weights and the adjusted criterion values are combined as a total cost or profit value [3] – [5] by network ranking algorithms. Factors of these six groups are presented one by one as follows:

Static network criteria: this group includes the following main factors: monetary cost, bandwidth, power consumption capability, security, bit error rate, jitter, HHO latency, etc., which have been widely used as criteria of network ranking in the literature [3] [4].

Dynamic network properties: this group includes traffic load information, signal strength, HHO signaling cost, etc. Considering their dynamic changes from time to time, their usage is complicated. HHO signaling cost is related with MT speed, mobility pattern, etc., which are also dynamic but can be measured by MT itself. Traffic load information is a pure network-side property, which has to be delivered to the MT before or during the network selection procedure. The change of certain network’s signal strength can be detected by the MT instantly after the network has been discovered.

VHO properties: this group includes two main factors: VHO latency and signaling cost, which are not properties of a single network but of a network rank. VHO signaling cost is dynamic, which is similar to HHO signaling cost. We use this group for both network ranking [16] [17] and VHO tradeoff.

Categorization of network-side criteria		Network-side criteria	Terminal-side requirements		
			Terminal properties	Customer preferences	Application QoS Levels
Static network criteria	ST	Bit Error Rate			Background
		Jitter			Streaming Conversational
		HHO Latency	Mobility		Conversational
	LT	Bandwidth		High Bandwidth	Streaming
		Security Level		High Security Level	Interactive
	SB	Monetary Cost		Low Monetary Cost	
		Power Consumption Capability	Battery State		
VHO properties	ST	VHO Latency			Conversational
	SB	VHO Signalling Cost	Mobility		
Dynamic network criteria	SB	HHO Signalling Cost			
		Traffic Load Information			
	LT	Signal Strength			

Figure 1. Categorization of factors for network selection.

Terminal properties group: battery state and MT speed are two main factors in this group. Battery state decides the weight of ‘power consumption capability’, while MT speed decides the weights of mobility-related criteria.

Customer preferences group: this group includes several options, e.g. low monetary cost, high bandwidth, high security level, etc. Customers should have the right to select one or multiple of the above options while purchasing the service or through their user-interface software. Once an option is selected, the weight of the corresponding network-side criterion should be adjusted.

Application QoS levels: applications can be divided into the following four levels based on their QoS requirements: conversational, streaming, interactive and background [10] [13]. Applications of different levels prefer to use large weights on different criteria. For example, video-streaming prefers bandwidth; Mobile VoIP prefers jitter and handover cost; while E-mail prefers security.

Moreover, network-side criteria can be further divided into four sub-groups based on their tiny differences: the larger the better (LB), the smaller the better (SB), larger than a threshold (LT) and smaller than a threshold (ST) [2]. Although the four sub-groups are generally processed similarly during network ranking [3] [4], their difference is still noticeable. Fig. 2 provides a comparison between two criteria: monetary cost (SB) and HHO latency (ST). When a customer uses Mobile VoIP and prefers low monetary cost, both of the two criteria have high weights according to our previous description. For the former, high weight is always appropriate; but for the latter, it is sometimes not. If the threshold is relatively large, i.e. TH1 in Fig. 2, high weight for HHO latency is not required. In a word, it’s necessary to consider the difference among the four groups when designing a network selection scheme.

B. *Weighting methods*

There are only a few weighting methods in the literature. The most common one is AHP, which is defined as a procedure to divide a complex problem into a number of deciding criteria and integrate their relative dominances with the solution alternatives to find the optimal one [3]. AHP is carried out with the following steps:

- Structuring the weighting issue as a decision hierarchy of all the criteria;

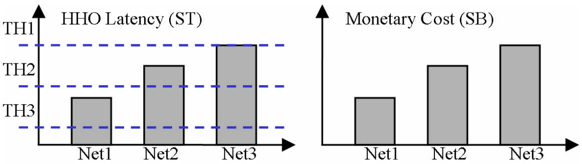

Figure 2. Comparison between ST (LT) and SB (ST) sub-groups.

- Comparing criteria pair-wise on each level in the hierarchy to obtain several matrices of relative priorities;
- Calculating the weights of criteria on each level as the eigenvector of each matrix;
- Synthesizing the above results as an overall vector of weights of all the criteria.

One of the key characteristics of AHP is the subjectivity of those pair-wise comparisons, that's why adjustment is required when the consistency ratio (CR) of the matrix of overall priorities is too large (e.g. >10%). It's worth mentioning that several sub-matrices of criteria on lower levels are used instead of a single matrix of overall priorities, so eigenvectors of these sub-matrices should be multiplied by their parent weights to obtain their overall weights at the last step [3].

AHP is combined together with GRA for network selection in [3]. The two procedures don't have any junction until the final decision making based on the calculated grey relational coefficient (GRC), so the weighting procedure of AHP considers nothing of network-side properties, normalization, fuzzification or network ranking algorithm. In other words, GRA algorithm in the combined scheme can be replaced by any other MCDM algorithm without any modification on the AHP side.

Beside AHP, entropy was also used as a weighting method in this issue, which is carried out as follows [6]. But this weighting method doesn't consider any terminal-side requirements, since the entropies are calculated based on only network-side criteria.

- Structuring an $m \times n$ value matrix, where m is the number of networks and n is the number of criteria;
- Normalization and fuzzification;
- Inversing SB and ST criteria into LB and LT groups for monotonicity;
- Calculating the entropy of each criterion based on $$e_j = [-1/\ln(n)]\sum_{i=1}^{n}\{r(i,j)\ln[r(i,j)]\},$$ where $r(i, j)$ is the normalized and adjusted value of the jth criterion of the ith network;

C. Normalization & Fuzzification

Since different criteria have different measurement units, normalization is treated as a necessary step of network selection. There are several methods of normalization [3] [15] [14] [19], which are compared in table I. In the table, N represents the number of networks, v_i represents the value of the ith criterion, and P_i represents its normalized value. The third method categorizes all the network-side criteria into three sub-groups, i.e. LB, SB and nominal-the-best (NB), so $NB(v_i)$ represents the nominal value of the ith criterion. The difference between the first and the third method is that the first one doesn't consider the NB group.

Fuzzification is another necessary step of network selection for two reasons: first, the relativity of normalized values of a network criterion may not denote their actual difference. For example, the bandwidth of WLAN (IEEE 802.11n) makes the normalized values of GPRS, EDGE and HSPA all smaller than 0.1, which badly reduces the three networks' difference of bandwidth. Second, tiny differences of several unimportant criteria may conceal the remarkable difference of a key criterion. For example, when the MT's speed is high, WLAN may be still preferred to UMTS, since most of its criteria are better which conceals its poor performance on the criterion 'handover cost'. Fuzzification could adjust the normalized values to overcome these problems, so it is generally used between normalization and network ranking modules [7] [15].

D. Network ranking algorithms

Up to now, MCDM algorithms that have been used for network ranking include SAW, MEW, GRA, TOPSIS, ELECTRE, and so on. As shown in table II, SAW, MEW, GRA and TOPSIS all calculate total cost or profit value of each network by combining several criteria with their weights [3] [7] [10] [13] [14]. Then, the networks will be ranked based on their total costs or profit values. In this table, M is the number of criteria, N is the number of networks, v_{ij} represents the value of the jth criterion of the ith network, w_j represents the weight of the jth criterion, R_j in GRA represents the most desired value of criterion j, and $R_{wj/bj}$ represents both the most desired and the most undesired values of this criterion.

ELECTRE is more complicated, which firstly uses pair-wise comparisons of all the 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, element (i,j) of a pair-wise comparison matrix, called concordance matrix, is calculated as a sum of weights of criteria in $CSet(i,j)$; and element (i,j) of another pair-wise comparison matrix, called discordance matrix, is

TABLE I. THREE METHODS FOR NORMALIZATION

$p_i = \dfrac{v_i - \min(v_i)}{\max(v_i) - \min(v_i)}$	$p_i = \dfrac{v_i}{\sqrt{\sum_{i=1}^{N} v_i^2}}$	$p_i = \dfrac{v_i}{\sum_{i=1}^{N} v_i}$

$$p_i = \begin{cases} 1 - \dfrac{|v_i - \max(v_i)|}{\max(v_i) - \min(v_i)} & \text{for LB} \\ 1 - \dfrac{|v_i - \min(v_i)|}{\max(v_i) - \min(v_i)} & \text{for SB} \\ 1 - \dfrac{|v_i - NB(v_i)|}{\max\{\max(v_i) - NB(v_i), NB(v_i) - \min(v_i)\}} & \text{for NB} \end{cases}$$

TABLE II. COMPARISON AMONG FOUR MCDM ALGORITHMS

SAW	$\arg\max_{i\in N} \sum_{j=1}^{M} w_j v_{ij}$
MEW	$\arg\max_{i\in N} \prod_{j=1}^{M} \left(v_{ij}\right)^{w_j}$
GRA	$\arg\max_{i\in N} \frac{1}{\sum_{j=1}^{M} w_j \left\lvert v_{ij} - R_j \right\rvert + 1}$
TOPSIS	$\arg\max_{i\in N} \frac{D_{wi}}{D_{bi} + D_{wi}}$, where $D_{wi/bi} = \sqrt{\sum_{j=1}^{M} w_j^2 \left(v_{ij} - R_{wj/bj}\right)^2}$

calculated as a sum of differences of criteria in $DSet(i,j)$ divided by a sum of differences of all the criteria. At last, elements of the two matrices are compared separately with $C_{threshold}$ and $D_{threshold}$ (e.g. both 0.5) to obtain a final pair-wise comparison matrix whose values indicate whether one network is preferred to another [14].

E. Load balancing schemes

In the context of HWNs, load balancing among these networks is always an essential issue. If traffic load information is considered as a criterion of network ranking, load balancing can be achieved at the same time of the network selection procedure. As this criterion is considered together with all the others, the performance of this load balancing scheme is related with its weight.

Network selection issue can also be modeled as a multiple-choice multiple-dimension knapsack problem (MMKP) with multiple knapsacks as follows [8]:

- Each traffic flow is mapped to a group of items, and the QoS level of the flow is mapped to an item in this group, so one item of each group will be selected;
- Each network is mapped to a knapsack with a capacity;
- The combined profit value of all the criteria is mapped to the profit of an item put into a knapsack, so an item has different profits while put into different knapsacks.

This issue can also be modeled as a game [9]:

- Each traffic flow is mapped to a game resource;
- Each network is mapped to a player;
- The combined profit value of all the criteria is mapped to the profit of a resource selected by a player, so a resource has different profits while selected by different players.

Both knapsack and game models could achieve load balancing at the same time of network selection, but they are generally used as network-side schemes.

III. FRAMEWORK

A. Framework of network selection

Based on the above study, we propose a framework of network selection, as shown in Fig. 3. This framework uses the six groups of factors as explained in section II.*A*. The three groups of terminal-side requirements are used for weighting, while the three groups of network-side criteria are adjusted by normalization and fuzzification and combined together based on the calculated weights. Static network properties are used the same as the related researches on this issue, but the usage of dynamic network properties and VHO properties requires further explanation.

Traffic load information is used as a criterion of static network properties, so that load balancing among these wireless networks can be achieved at the same time.

Signal strength is also used as a criterion of network ranking, but we define specifically for the case when the signal strength of a network becomes 0. In that case, instead of changing the value of its criterion ‘signal strength’ into 0, we directly ignore this network from the list of available networks.

HHO latency, HHO signaling cost, VHO latency and VHO signaling cost are considered as one single criterion ‘handover cost’, which is used together with other criteria. Thus, our framework can select the appropriate network when the MT has different mobility properties. However, the usage of this factor is a hot potato, because costs of both HHO between hotspots and VHO among different networks are complicated to be evaluated. For example, VHO cost is related with network ranks, not networks. Now that n networks lead to $n!$ ranks, we have to calculate VHO costs of these $n!$ ranks. Moreover, the calculation of VHO cost of each rank involves a (2^n-1)-state Markov chain and $2n(n-1)$ different VHOs [16] [17].

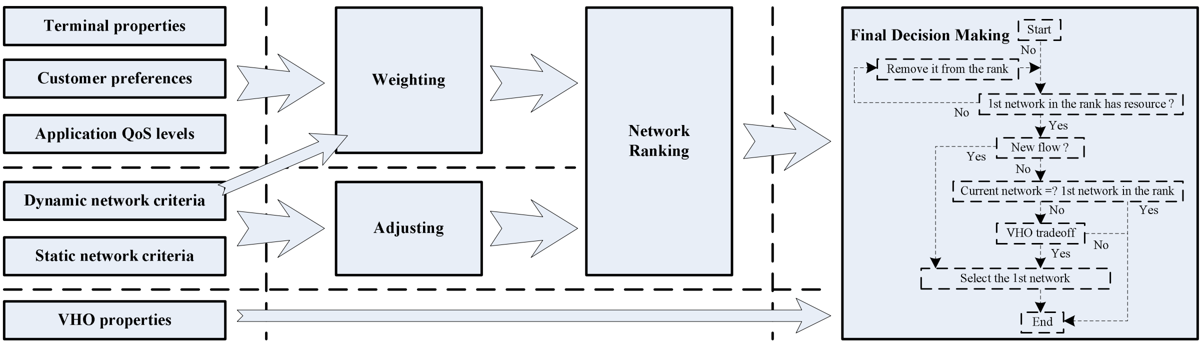

Figure 3. A framework of network selection.

In the weighting module, certain weighting method, e.g. AHP and entropy, is used to calculate the weights. AHP uses the three groups of terminal-side requirements, while entropy uses the criteria. In the adjusting module, all the criteria are adjusted by normalization and fuzzification. In the network ranking module, adjusted criteria are combined according to their weights by certain network ranking algorithm, e.g. any MCDM algorithm.

Then, the final decision making module gathers all the information and makes the final decision. For a new single-homed MT (SMT) or a new traffic flow of a multi-homed MT (MMT), the first-rank network will be selected as long as it has resource. For an on-going SMT or an on-going traffic flow of a MMT, VHO tradeoff between benefit and cost of handover is considered. Since the networks have been ranked in the network ranking module, the benefit is calculated based on the difference between the best network and the on-going network. If the on-going network is found still the best network in the new situation, there is of course no need to do any VHO tradeoff.

B. Simulation results

Based on the proposed framework, we established a network selection simulator to prove its feasibility. In the following simulation, nine criteria are used: monetary cost (M), bandwidth (B), power consumption capability (P), security level (S), traffic load information (T), signal strength (SS), bit error rate (BER), jitter (J) and handover cost (HC). Within these criteria, LT and LB sub-groups are inversed into ST and SB for monotonicity. AHP, as described in section II.*B*, is used for weighting. Five MCDM algorithms presented in section II.*D* are simulated.

In our simulation, we consider a heterogeneous environment including the following technologies: WCDMA, EDGE, GPRS, IEEE 802.11b, IEEE 802.11g, IEEE 802.11n, WiMax, Bluetooth. An SMT and an MMT move together within these networks' coverage. The former can only connect to the Internet through one technology at one time, so the selection of its best network should consider simultaneously all the applications together. By contrast, the latter is capable of connecting through multiple of the above technologies, so different technologies are selected for different applications if necessary.

As shown in Fig. 4, a series of scenarios are designed for simulation. Two colleagues using separately SMT and MMT in a heterogeneous environment consisting of the above technologies are doing the following consecutive affairs:

1) in their office, surf websites and check e-mails (App1);
2) in a meeting room of their company, where there have been a lot of people using Blue-tooth, so its traffic load is almost saturated;
3) in a coffee house, where there is no Bluetooth, IEEE 802.11n or IEEE 802. 11g;
4) in a taxi to a university to give a presentation, the speed is high;
5) in the taxi, continue App1 and start video conference (App2);

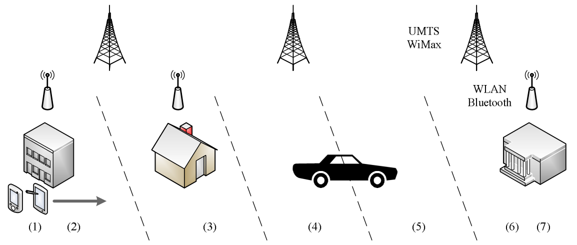

Figure 4. Scenarios in our simulation.

6) in an auditorium of the university, the speed is low, and the video conference is continued;
7) in the auditorium, both App1 and App2 are continued, but the battery power becomes low.

Based on AHP, weights of the two MTs are calculated as shown in table III. For both SMT and MMT, scenarios 1, 2 and 3 use the same group of weights, while scenarios 4, 5, 6 and 7 use different groups of weights. Moreover, for MMT, App1 and App2 use different groups of weights in scenarios 5, 6 and 7.

Fig. 5, 6 and 7 shows separately the SMT's selection results and the MMT's selection results for App1 and App2. In scenarios 1 and 2, IEEE 802.11g or Bluetooth is selected, since they have low price than most of the others. Then, some high performance technologies are not available any more, so IEEE 802.11b is selected based on its low price and better power consumption capability. ELECTRE selects WiMax in scenario 3, which we believe is also reasonable, since it has a better security level than WLAN. In high-speed scenarios, GPRS is selected for applications which don't request large bandwidth, while WiMax is selected for video-conference. At last, Bluetooth should be selected when the battery power becomes low, but there is also a large probability to select WLAN because the video-conference is still continued.

Although different MCDM algorithms may lead to tiny difference in a given scenario, the proposed framework can always provide appropriate and reasonable network selection results after different network-side and terminal-side changes. Further comparisons among factors, weighting methods and MCDM algorithms show that every component greatly affects network selection results [18].

TABLE III. WEIGHTS IN THE SIMULATIONS (%)

Scenario			M	B	P	S	T	SS	BER	J	HC
1 - 3			33	3	10	21	9	4	13	4	3
4			27	2	7	16	6	3	9	3	27
SMT	5		21	21	5	11	9	2	6	4	21
SMT	6		25	25	7	14	12	2	7	6	2
SMT	7		17	17	37	10	7	2	4	4	2
MMT	5	App1	27	2	7	16	6	3	9	3	27
MMT	5	App2	23	23	7	3	9	3	3	8	21
MMT	6	App1	33	3	10	21	9	4	13	4	3
MMT	6	App2	28	28	9	4	10	4	4	9	4
MMT	7	App1	22	2	40	14	9	3	6	2	2
MMT	7	App2	20	20	37	4	6	2	2	7	2

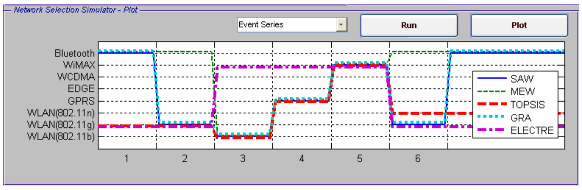

Figure 5. Best networks for SMT in different scenarios.

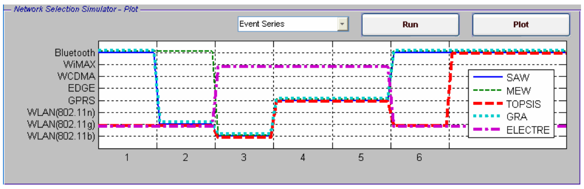

Figure 6. Best networks for App1 of MMT in different scenarios.

Figure 7. Best networks for App2 of MMT in different scenarios.

IV. CONCLUSIONS AND IMPORTANT ISSUES

This paper firstly provided a survey of the network selection issue by dividing it into five components. Factors were categorized into groups and sub-groups in order to facilitate their usage when designing network selection schemes; existing weighting methods were described, which showed that further research effort in this domain was required; network ranking algorithms were presented and compared to show their similarity and difference; normalization, fuzzification and load balancing schemes were also summarized. Then, we proposed a framework which employs six groups of factors, combines the surveyed five components, and covers a large number of recent propositions on this issue. At last, we established this framework by simulation, which shows its feasibility for both SMT and MMT in different kinds of scenarios. Some issues that, we believe, require further study are listed in table IV.

TABLE IV. IMPORTANT ISSUES IN THE SCOPE OF THE PROPOSED FRAMEWORK

Factors	Mobility: how to calculate and use HHO and VHO costs as a criterion in the MCDM algorithms [16] [17]
	Traffic load: how to decide this dynamic factor's importance in different scenarios [18]
	Tradeoff: between benefit of using more factors and complexity of the scheme
Weighting	AHP: the pair-wise comparison matrix in this method is subjective, which is not easily generated by the MTs
	Other methods: other weighting methods should be tried, and the relationship between weighting and MCDM algorithms is not clear
MCDM algorithms	Comparison: these algorithms lead to different selection results [10] [18]
Load Balancing	Comparison: game, knapsack, using traffic load information as a criterion of network ranking, etc.
NEMO	Competition among different mobile network nodes
	Network selection schemes deployed on a mobile router
Scheme Design	Terminal-side solution vs. network-side solution

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Dépôt légal : 2009 – 3ème trimestre
Imprimé à l'Ecole Nationale Supérieure des Télécommunications – Paris
ISSN 0751-1337 ENST C (Paris) (France 1983-9999)

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