A Novel Algorithm for Selecting Multimedia Network Connections in Next Generation Networks

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***Abstract*— In the past, Always Best Network Connection (ABNC) has been presented to selecting an access network based on the characteristics of communication session in heterogeneous wireless networks. The novelty of ABNC is to consider both source and destination access networks when a voice session is being setup. However, it is not suitable for multimedia service, which consists of video and data in addition to voice. This paper presents an Always Best Multimedia Network Connection (ABMNC) model to support multimedia services. ABMNC is an integration of a Multiple Attribute Decision Making (MADM) problem and a utility-based Multiple Knapsack Problem (MKP). We present a hybrid Analytic Hierarchy Process (AHP) and Simple Additive Weighting (SAW) scheme to solve the problem. Finally, a heuristic algorithm was proposed to reduce the complexity of access network selection. The simulation results show that the presented approach performs better than current approaches.**

Keywords-4G; ABC; ABNC; MADM; AHP; SAW; Utility.

I. INTRODUCTION

Nowadays, various access networks such as General Packet Radio Service (GPRS) [1], Long Term Evolution (LTE) [2], Microwave Access (WiMAX) [3], and Wireless Local Area Networks (WLAN) [3] have been deployed widely. Each access network provides different levels of Quality of Service (QoS), in terms of bandwidth, mobility, coverage area, and cost to the mobile users. Next-generation networks (NGN) commonly known as 4G integrate these different access technologies and support all IP-based traffic. Indeed, 4G users will be able to connect seamlessly to various access networks that offer the best possible quality at any time and any place.

Despite all potential advantages of 4G, selection of the best network connection remains one of the most important concerns and critical issues. Based on user preferences, the best access network must be selected to establish connection between source handset and corresponding handset. A widely accepted approach called Always Best Connected (ABC)[4] has been proposed to solve this problem. ABC is user-centered which means it makes users always choose the best available access networks at any place and any time. However, in many situations choosing a good access network is not good enough. For example, voice communication is charged not only based on source access network but also on the chosen corresponding access network.

ABNC [5] extends ABC to let users select the best network connection, which consists of the source and the destination access network pair when handsets are equipped with multiple interfaces. It has been shown that ABNC indeed works better to meet user's requirements. However, ABNC is designed for voice sessions and is not suitable for multimedia services for the following reasons: Firstly, a multimedia session can be established on many paths and has more than one media type and thus, we may choose more than one path and have to assign each media type to the chosen paths, which is not considered in ABNC. Secondly, a multimedia session contains media type such as video that requires much larger end-to-end bandwidth than a voice session. This paper presents a more flexible model called Always Best Multimedia Network Connection (ABMNC). ABMNC extends ABNC to support multimedia services and deals with different multimedia sessions such as video, voice, and data. ABMNC constructs multiple end-to-end connections between users, and then chooses the best configuration that comprises one or more connections with respect to multiple media sessions.

In this study, ABMNC is formulated as a Multiple Attribute Decision Making (MADM) problem. The ABMNC decision hierarchy chooses a set of network connections based on attributes such as cost, quality, security, and power consumption. The ABMNC decision hierarchy weights all media types in a multimedia service and then assigns a media type to a network connection. In order to reduce the complexity of MADM and have a reasonable number of alternatives, the MADM hierarchy is decomposed into many iterated sub-MADM hierarchies. Also, the media assignment problem is formulated as a utility-based Multiple Knapsack Problem (MKP) and a heuristic approach is presented to solve the problem. Simulation results show that our heuristic approach can perform well as compared with that of an exhaustive searching scheme.

This paper adds contributions to [6] by introducing a heuristic path selection algorithm. Also, simulation was performed to study the performance of our presented algorithms.

The rest of the paper is organized as follows. Section II summarizes related work. Section III describes the multimedia session selection and formulates the problem.

Section IV depicts the proposed methodology, and illustrates a hybrid scheme of SAW and AHP. ABMNC performance is evaluated in Section V. Finally, Section VI concludes the paper.

II. RELATED WORK

ABC has been extensively studied by a number of researchers. The concept and architecture of ABC are described in [3]. In [7], the ABC problem is formulated as a variation of the Knapsack problem with multiple knapsacks, and further proved it to be NP-Hard. Given a set of flows, in [8], authors formulate ABC as a variant of bin packing problem and present a series of approximation algorithms based on First Fit Decreasing (FFD) algorithm that select a network to meet user's QoS requirements and with maximal admitted flows for a user. However, the approach used in [7] addresses the problem from a network perspective. What it is maximized is the admitted flow, not the user satisfaction. Roy et al. [9] intends to achieve ABC over WLAN and WiMAX by using a new mechanism to detect QoS support of the underlie networks.

The work in [10, 11] take multiple criteria into consideration, however, still leaving some problems. For instance, weight elicitation has been ignored; and the rank irregularity problem is not addressed. [12] considers both user preference and attributes of access networks and formulate ABC as a problem of MCDM. In addition, in [13-15], an access link selection management is proposed to incorporate user preference profiles as a part of the selection policies.

Many hybrid approaches have been used in solving ABC. Liu [16] proposes a hybrid ANP [17] with RTOPSIS [18] based on several decision making algorithms to select the best candidate networks(s) from the user perspective. Mohamed et al. [19] presents selection strategy based on ANP and TOPSIS while [20] integrates AHP and TOPSIS in selecting a network. In [21], four MADM algorithms, namely SAW, MEW, TOPSIS and GRA, are simulated to show the impact of criterion's weight on the coefficients. They solve the rank irregularity problem and eliminate the interdependence between criteria. All previous researches in ABC focus on source access network selection, which appropriates when a multimode handset is in a standby mode. However, when a service session is being set up, ABC is no longer efficient as the performance of a service session depends not only on the source access network, but also on the corresponding destination access network.

In [5], ABNC is proposed to enable users with multimode handsets to select the best network connection for a voice session, which consists of source and destination access network pair, to satisfy quality constraints and users' preferences. However, when a multimedia session with more than one media type is being setup, ABNC cannot meet the need. Thus, a more comprehensive model than ABNC is required to meeting multimedia session services.

III. MULTIMEDIA SESSION

A. Problem Definition

Given a pair of communicating parties, each is equipped with n interfaces. Then there exist n^2 possible network paths or connections between them. Media session contains video, voice, and data, and each can take any one of the connections. Assume one medium can pass only on one connection and more than one medium can share one path when the path has sufficient bandwidth. With this assumption, we have $(n^2)^3 = n^6$ possible transmission configurations.

Given source handset S and corresponding handset C. Let A_i^S and A_j^C denote access networks of source handset and access networks of the corresponding handset, respectively. Let S_{ij} denote a connection established from source handsets interface i to corresponding handset's interface j, and be defined as $S_{ij} = (A_i^S, A_j^C)$. For example, $S_{UMTS,WiFi}$ means the connection is established from UMTS interface of source to the WiFi interface of corresponding. Due to the nature of multimedia session, ABMNC considers more than one connection. Let k be a set of configurations that indicates how caller and callee are connected through their access networks. Then, the configuration $k = (S_{UMTS,WiFi}, S_{WiFi,WiFi})$ means there are two connections established from UMTS and WiFi interface of source to the WiFi interface of destination. Characteristics of a multimedia session are determined by source and destination access networks. Connections can be characterized by cost, power, security level, and utility.

- Cost (C_k): The cost information can be acquired from ISP. Charging depends on both source and destination networks, we represent cost as $C(S_{ij}) = C(A_i^S, A_j^C)$. The cost should be accumulated on the number of interfaces used by both sides during communication.
- Power (P_k): The energy consumed per unit of time. It depends not only on the type of access networks of source handset but also on the number of interfaces used during a call.
- Security Level (SL_k): The security level goes from UMTS, WiMAX, WiFi in a descending order. Since a path consists of a number of access networks, so, the access network with minimal security level will determine security level of the path $SLk(S_{ij}) = \min\{SL(A_i^S), SL(A_j^C)\}$.
- Utility (U_k): The quality of a multimedia session is represented by utility. Here, we use the data rate as the quality index. The utility function U_k for configuration k will be defined in the next section.

The best configuration S^* is selected by comparing scores of k , which is the addition of the normalized contribution from each criterion multiplied by the weight factors. S^* is defined as follows.

$$\mathrm{S}^* = \arg_{\mathrm{k}} \max(\mathrm{w_c}\, \mathrm{C_k} + \mathrm{w_p}\, \mathrm{P_k} + \mathrm{w_u} \mathrm{U_k} + \mathrm{w_{sl}} \mathrm{SL_k}), \quad \mathrm{s.t}\ \mathrm{CB} > \mathrm{T_B} \text{ and } \mathrm{CS} < \mathrm{T_s}\ , \tag{1}$$

where w_c, w_p, w_{sl}, and w_u are weights for criteria cost, power, utility, and security level, respectively. CB is the set whose elements are adequate when they are bigger than a threshold T_B . Bandwidth is an example. Also, CS is the set whose elements, such as delay, are adequate when they are smaller than a threshold T_S . Based on (1), ABMNC is modeled as a MADM problem. The goal of the MADM hierarchy is to select the most suitable configuration k for transmission at the top level and solution alternatives are located at the bottom nodes. More information on mathematical model is presented in [6].

B. Utility-Based Media Assignment

In this section, a utility-based measurement scheme is presented to evaluate the quality of multimedia services, based on which, the media session assignment is formulated as a MKP, which is a generalization of the standard knapsack problem from a single knapsack to m knapsacks with different capacity. The objective is to assign each item to at most one of the knapsacks such that none of the capacity constraints are violated and the total profit of the items put into knapsacks is maximized.

The design of the utility functions is to strike a balance between system utilization and system QoS requirements. Let U_k^m be the utility function of a given configuration k for some medium m, where $m \in \{video, voice, data\}$ and be defined as follows.

$$\mathrm{U_k^m} = w_m \log_2(1 + \frac{\mathrm{x_m}}{\mathrm{b_m}}), \tag{2}$$

where X_m and b_m are the allocated and requested B.W. for media m, respectively. w_m is media weight which is obtained from AHP. Because humans are more sensitive to the voice (speech) than video, and data is considered to be the least important, the weight for video, voice, and data are $w_{voice} > w_{video} > w_{data}$.

In MKP, every path of different bandwidth between the caller and callee is considered as a bucket of different size. Each medium of different bandwidth requirement is considered an object of different size that to be included in one of many possible buckets. The objective is to assign objects to the available buckets such that we can get the maximal utility value while each bucket is not overflowed. Thus, given N different paths, the media assignment problem of the ABMNC is defined as follows.

$$\begin{aligned} U_k &= \max_{X_m} \sum_{i=1}^{N} \sum_{m} U_k^m x_{im} \\ &= \max_{X_m} \sum_{i=1}^{N} \sum_{m} w_m \log_2\left(1 + \frac{\mathrm{x_m}}{\mathrm{b_m}}\right) x_{im}, \\ & s.t. \sum_{m} X_m x_{im} \le W_i\ , \\ & \sum_{i=1}^{N} x_{im} = 1, x_{im} \in \{0,1\}, \\ & \sum_{m} w_m = 1\ ,\ T_m \le \frac{\mathrm{x_m}}{\mathrm{b_m}} \le 1\ , \end{aligned} \tag{3}$$

where U_k is the utility or scores acquired by optimizing the allocated rate for a configuration k comprising a set of dedicated connection(s), x_{im} denotes the m^{th} kind of media object assigned to the i^{th} path, and W_i denotes the available bandwidth for path i.

The first constraint ensures that the total allocated bandwidth to each path i will not exceed its limit (knapsack weight), and the second one indicates that each medium can only be assigned to one path. X_m / b_m is ranged from zero to one, so, the maximal value of U_k is one. T_m limits X_m to have a minimal threshold value to ensure an acceptable quality level for media m. A connection is feasible only if it has bandwidth larger than the threshold value.

IV. ABMNC

Selecting the best connection for multimedia session is a complicated process due to intensive comparison of a large number of alternatives. In this section, we propose a hybrid scheme of SAW and AHP in order to reduce the number of configurations (alternatives) and hence the computation complexity. AHP is used to decide relative importance of criteria and media, which is then used by SAW for scoring.

When the source handset want to start multimedia session it initiates a network discovery procedure to detect all available networks and candidate paths S_{ij} . These paths are input to our heuristic algorithm for path selection. To speed up the computation of MADM, we integrated the path selection scheme with our hybrid AHP and SAW approach. The hybrid AHP and SAW rates the path alternatives by considering all criteria, except utility, to produce a partial score first. We sort all candidate paths by their partial scores in a descending order. Then, we select paths based on their contribution on utility value or their bandwidth. After the heuristic algorithm selects a configuration, the overall score is computed by merging the utility value with media assignment. Fig.1 shows the process of multimedia session selection.

A. SAW-AHP hybrid scheme

AHP illustrates the importance of each criterion by determining the relative weights of the compared criteria where weights are decided according to user's preferences. Since our approach deals with media sessions, AHP weights both criteria, w_c, w_p, w_{sl}, and w_u, and media which is used during media assignment.

Table I shows how AHP weights each media. Voice row shows that voice is twice as important as video, three times as important as data, and equal to itself. Video row shows the video is twice as important as data. We use Arithmetic Mean of the Normalized Column Vectors (AMNCV) and get $w_{video} = 0.297$, $w_{voice} = 0.539$, and $w_{data} = 0.164$. By a similar process, we can readily obtain weight for w_c, w_p, w_{sl}, and w_u from AHP. AMNCV is defined as follows.

$$w_i = \frac{1}{|m|}\sum_{j=1}^{|m|}\frac{a_{ij}}{\sum_{i=1}^{|m|} a_{ij}} \quad i, j = 1,2,\ldots|m|, \tag{4}$$

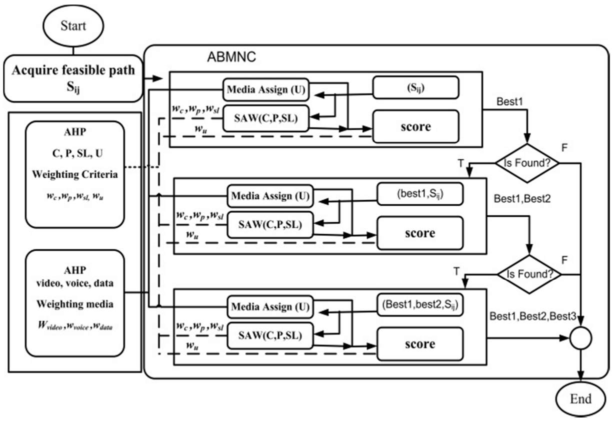

Figure 1. Process of multimedia session selection

TABLE I. COMPARISON MATRIX OF MEDIA WITH RESPECT TO THE CRITERION UTILITY

Utility	Video	Voice	Data
Video	1	1/2	2
Voice	2	1	3
Data	1/2	1/3	1

SAW is used to produce the overall score of an alternative and is computed as the weighted sum of all the attribute values. In our study, we use parameters for different access technologies and user preferences to construct a decision matrix with respect to cost, power, and security level. Then, we normalized the table based on whether the criteria is beneficial, e.g., security and utility or non-beneficial, e.g., cost and power. The best configuration is obtained by comparing the weighted average of all alternatives from the normalized decision matrix as follows.

$$MAX\sum_{j=1}^{m} w_j r_{ij}, \tag{5}$$

M denotes the number of criteria and w_j is the weight of the j^{th} criterion. r_{ij} is the normalized score of the j^{th} criterion of the i^{th} alternative.

B. Heuristic Algorithm.

Our heuristic algorithm classifies the sub-MADM hierarchies into three modes, single-path, dual-path, and triple-path. The first mode takes one path while the second takes two paths, and so on. Each mode outputs the best configuration as input to next mode if it exists. The next mode tries to find a better result by combining the input best configuration and one of the remaining S_{ij}. Note that each mode re-considers all remaining paths again for a better result. If a better configuration cannot be found, the result of the previous mode is the result. Also, the connection fails if nothing is found in the single-path mode. Table II shows notations used in the heuristic algorithm.

The heuristic algorithm is designed to choose the best configuration from a set of ranked paths for media transmission. The algorithm considers first the path with a larger score without utility value, and then a path with a larger bandwidth. It reduces the number of candidate paths by deleting a path with a lower bandwidth and ranking compared with the others.

Single-path, dual-path, and triple-path mode are shown in Algorithm 1. We specify the rules for the dual-path and the triple-path mode with some replacements to simplify the pseudo code because they're based on the same concept of the single-path mode. For example, SAW(f_i, f_{best1}) at line 19 means scoring a new alternative (f_i, f_{best1}) based on results at line 3.

ALGORITHM 1: Single-path heuristic path selection algorithm

```
1:  BEGIN
2:      $S_k^* = \varnothing$          /* $score_{all}(S_k^* = \varnothing)$ is zero*/
3:      SAW ($F$)
4:      $\forall f_i \in F$ : Sort $f_i$ in decreasing order by score.
5:      $\exists f_i \in F$ : $B(f_i) \geq \sum b_m$ targets a $f_i$ which has higher order
        and remove others lower than it from $F$ .
Step(1)
6:      $Q = F$
7:      For $f_i$ in $Q$ remove $f_{i+j}$ from $Q$
            $s.t. B(f_i) \geq B(f_{i+j}),\ 1 \leq j \leq |Q|$ . Endfor
Step(2)
8:      For $f_i$ in $Q$
9:          SPRA ($f_i$)
10:         Get the overall score of $f_i$
11:         If ( $score_{all}(f_i) > score_{all}(S_k^*)$ ) $S_k^* = f_i$ Endif
12:     Endfor
```

```
Step(3)
13:        If (IsUpdated( $S_k^*$ ) is TRUE)
14:            $f_{best1} = S_k^*$
15:            Jump Dual-path
16:        Else Exit
17:        Endif

                 Dual-path
18:  Repeat Step(1) but replace $Q = F$ by $Q = F - \{f_{best1}\}$ ,
19:  Repeat Step(2) but insert SAW $(f_i, f_{best1})$ after line 8,
20:  Replace all $f_i$ by $(f_i, f_{best1})$ and SPRA by DPRA.
21:  Repeat Step(3) but replace $f_{best1}$ by $(f_{best1}, f_{best2})$ ,
22:  Replace Dual-path by Triple-path.
                 Triple-path
23:  Repeat Step(1) but replace $Q = F$ by $Q = F - \{f_{best1}, f_{best2}\}$ .
24:  Repeat Step(2) but insert SAW $(f_i, f_{best1}, f_{best2})$ after line 10,
25:  Replace all $f_i$ by $(f_i, f_{best1}, f_{best2})$ and SPRA by TPRA.
26:  END
```

TABLE II. SUMMARY OF NOTATION FOR OUR HEURISTIC ALGORITHM

Symbol	Meaning	Symbol	Meaning
S_k^*	The final transmission configuration	*score*	Retrieving the saved partial score of an input configuration
B	Available bandwidth of some path	SPRA	Single-path rate allocation (media assignment)
F	A set of candidate paths.	DPRA	Dual-path rate allocation (media assignment)
f_i	Element in sorted F	TPRA	Triple-path rate allocation(media assignment)
Q	A set of good candidate paths	f_{best1}	The best result found in single-path mode
SAW	Score input configurations without utility	(f_{best1}, f_{best2})	The best result found in dual-path mode
$score_{all}$	Retrieve the saved overall score of an input configuration		

V. PERFORMANCE EVALUATION

This section evaluates the performance of our proposed solution, ABMNC, through simulations. Fig.2 shows our simulation environment in which two handsets are willing to establish a multimedia session. Each handset is equipped with three interfaces. We assume there are nine feasible paths S_{ij} which satisfy the minimum bandwidth requirement, and S_{1j}, S_{2j}, S_{3j} denote the paths from source handset's interface of UMTS, WiMAX, and Wi-Fi to the j^{th} interface of destination, respectively.

Default simulation parameters used to analyse the performance are listed in the Table III. For different access technologies, the cost is referred by recent ISP charging mechanism, the power consumption, i.e., standby time is based on the specifications of some representative multimode handsets, and the relative values of security level are from some wireless technical reports. We assume monthly charged cost, and the cost is counted in both caller and callee no matter who initiates the call. Media weights are calculated from AHP.

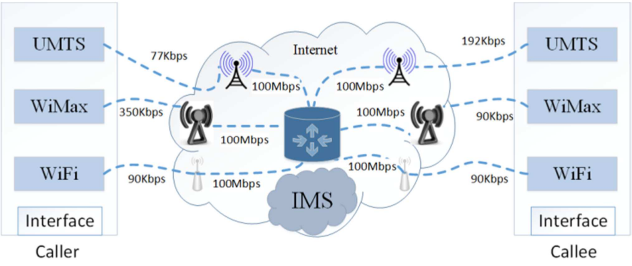

Figure 2. Environment for analysis

TABLE III. SIMULATION PARAMETERS

Number of handsets	2	**Cost for caller/UMTS**	0.0003$/s
Number of interfaces	3	**Cost for caller/WiMax**	0.0005$/s
Number of feasible paths	9	**Cost for callee/Wi-Fi**	0.0001$/s
Power/UMTS	420mins	**Cost for callee/UMTS**	0.0005$/s
Power/WiMax	180mins	**Cost for caller/WiMax**	0.0003$/s
Power/Wi-Fi	210mins	**Cost for callee/Wi-Fi**	0.0002$/s
Security/UMTS	Moderate	w_{video}	0.297
Security/WiMax	High	w_{voice}	0.539
Security /Wi-Fi	Low	w_{data}	0.164

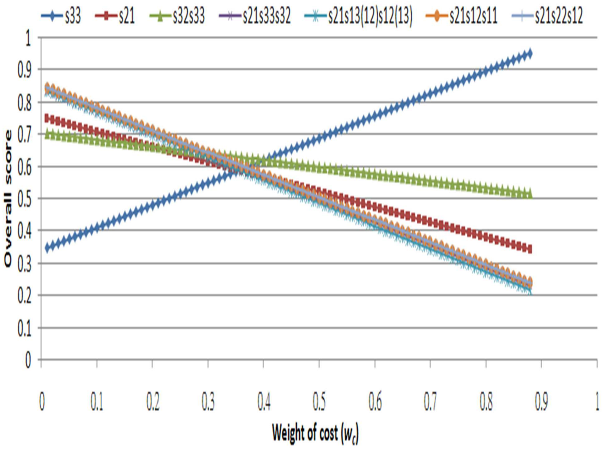

Figure 3. Scores of various alternatives

We compare ABMNC results with an exhaustive search (EX) method. The EX is a very general problem-solving technique that examines all configurations as alternatives. EX takes a large amount of time to complete a decision making when the number of candidates is large. In the simulation, the user is more interested in quality and cost, and cares less about security or power. Thus, based on user's preferences we set $w_p = 0.05$, $w_{sl} = 0.05$, and $w_u + w_c = 0.9$. Fig. 3 illustrates the scores of all possible configurations at various weights of cost w_c and the respective weight of utility w_u.

Fig. 4 illustrates the decision making results by ABMNC and EX. We observed that the result converges to S_{33} when w_c increases because S_{33} has the smallest cost among all alternatives, and the cost dominates the overall scores when w_c is getting large. Thus, S_{33} is the best connection for general users that want to save money. On the contrary, configuration (S_{21},S_{22},S_{12}) and (S_{21},S_{12},S_{11}) are recommended for the users who strongly demand quality as w_u becomes large. One can observe that the overall score changes when weights change, which is a desirable feature for a scoring system. Note that the chosen configuration is not shown in this figure.

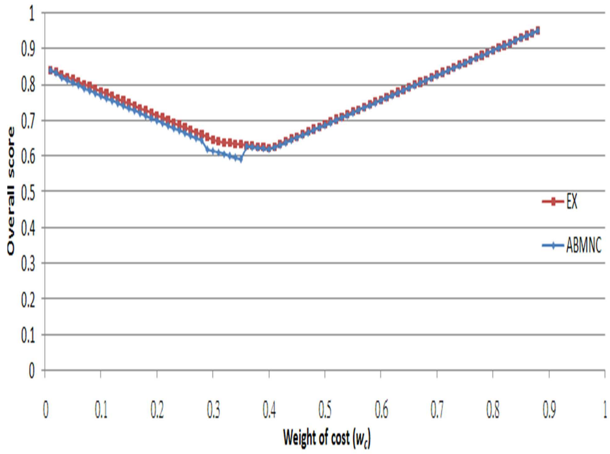

Figure 4. Comparison between ABMNC&EX

It can be observed from Fig. 4 that results are overlapped with one another except in the interval $w_c = [0.25, 0.35]$. This is due to the nature of the heuristic path selection algorithm. In this interval, ABMNC does not perform as well as the EX. EX chooses the dual-path or triple-path configurations rather than single-path S21 by ABMNC.

VI. CONCLUSION AND FUTURE WORK

In this paper, a new approach called ABMNC was presented to selecting best network connection for multimedia communication. Unlike all previous approaches, in ABMNC the problem was formulated as a MADM hierarchy with MKP media assignment. The complexity of the selection process was tackled by combining our hybrid SAW and AHP scheme with our novel heuristic algorithm, which all together work on reducing the number of alternative paths, and thus simplifying the computation complexity. Simulation results show that ABMNC can choose network connections that match well with EX most of the time.

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