A Novel Multiple Attributes Decision Making Approach For Multimedia Session Selection

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Abstract— **The fourth generation (4G) network integrates various access technologies, such as UMTS, WiMAX, and WLAN. In the 4G environment, a handset with multiple interfaces can switch among access networks to achieve ubiquitous service. However, how to select the best access network is critical for users to obtain their preferred services. In the past, Always Best Network Connection (ABNC) has been presented to select an access network based on properties of communication session, which is composed of both source and destination access networks. Nevertheless, ABNC fails to consider current multimedia services, which require an end-to-end bandwidth much larger than that of voice sessions and media types, such as voice, video, and data. In this paper, an extension to ABNC is presented to support multimedia services by exploiting parallel paths between multimode handsets. We formulated the problem as a Multiple Attributes Decision Making (MADM) hierarchy with a utility-based media assignment and utilized a hybrid Analytic Hierarchy Process (AHP) and Simple Additive Weighting (SAW) scheme to solve the problem. Finally, an example is illustrated to show how the scheme works.**

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

I. INTRODUCTION

The main feature of 4G is in its ability to integrate different access technologies, such as universal mobile telecommunication system (UMTS) [1], Worldwide Interoperability for Microwave Access (WiMAX) [2], and wireless local area networks (WLAN) [2], leading us to all-IP networking era. The vision of a 4G mobile system is to integrate various radio access technologies (RATs) into a common network called the open wireless architecture (OWA) platform.

To enjoy the convenience of 4G, nowadays, handsets are equipped with multiple interfaces and can switch among various access networks to achieve ubiquitous service. However, 4G networks still face a number of challenges; one of them is to select the best access network based on user preferences.

An earlier solution was using Always Best Connected (ABC) schemes. ABC enables a user to choose the best available access network that best suits his/her needs based on receiving signal strength (RSS), cost, quality, security, etc. Later on, a new paradigm called Always Best Network Connection (ABNC) is presented. ABNC selects an access network based on properties of communication session, which is composed of both source and destination access networks. It has been proved that ABNC indeed works better to meet user's requirements [3] .

ABNC, however, has a number of deficiencies when it is applied for multimedia communications: first, ABNC considers only RSS as an index of quality; it does not consider other indices, e.g., bandwidth. Second, ABNC does not exploit path diversity between the source and the destination; it only chooses a path for end-to-end communication between two peers. Finally, ABNC only considers voice sessions, which only require small bandwidth. Thus, ABNC cannot meet the need of multimedia communications, which require exchange of various media data such as video that needs a large bandwidth. Thus, a more comprehensive model than ABNC is required for multimedia session services.

In multimedia communication, multiple connections need to be set up between the source and the destination for exchange of various media type of data, such as data, audio, and video. Besides, many paths may exist between handsets with multimode interfaces. Thus, each connection may be set up on different path. Therefore, to support multimedia services, the new model must allow us to select which path or set of paths for connection setup to best meet user's preference. In this paper, we extended ABNC and presented a new paradigm called Always Best Multiple Network Connections (ABMNC) for multimedia services.

ABMNC is formulated as a Multiple Attributes Decision Making (MADM) problem. The ABMNC decision hierarchy chooses a combination of network connections instead of each individual connection based on a number of attributes such as cost, quality, security, and power consumption. The ABMNC decision hierarchy also weights each media type in a multimedia service according to its significance in communication. To assign a media type on a network connection with best communication quality, the media assignment problem was formulated as a utility-based Multiple Knapsack Problem (MKP). Furthermore, to reduce the complexity of the MADM and have a reasonable number of alternatives, the original MADM hierarchy is decomposed into three iterated sub-MADM hierarchies. A novel hybrid AHP and SAW scheme was presented to efficiently solve the iterative strategy. Finally, an example is used to illustrate how ABMNC works.

In summary, this work has three contributions: A new paradigm called ABMNC is defined; a utility-based media assignment problem based on the significance of each media on multimedia communication is formulated as a MKP

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problem; an efficient iterative problem solving scheme that integrate SAW, AHP and path selection is presented to solve ABMNC.

The rest of the paper is organized as follows. Section II summarizes related work. Section III describes and formulates the multimedia session selection problem. Section IV depicts the proposed methodology, and a hybrid scheme of SAW and AHP is presented. An example to illustrate ABMNC is given 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 [4]. V. Gazis et al. [1] formulates the ABC problem as a variation of the Knapsack problem with multiple knapsacks, and further proved it to be NP-Hard. Given a set of flows, [5] formulate ABC as a variant of bin packing problem and presents a series of approximation algorithms based on First Fit Decreasing (FFD) algorithm that selects a network to meet user's Quality of Service (QoS) requirements and with maximal admitted flows for a user. However, the approach used in [1] addresses the problem from a network perspective. What it is maximized is the admitted flow, not the user satisfaction. J. Jackson et al. [6] intends to achieve ABC over WLAN and WiMAX by using a new mechanism to detect QoS support of the underlie networks.

In [7], both user preferences and attributes of access networks were considered, and ABC was formulated as a problem of MCDM. A hybrid Analytic Network Process (ANP) [8] with RTOPSIS [9] model based on several decision making algorithms to select the best candidate networks from the user's perspective is proposed in [10]. It solves the rank irregularity problem and eliminates the interdependence between criteria. All previous researches in ABC focus on source access network selection, which is appropriate 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 access network.

In [3] , ABNC was proposed. ABNC enables 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 multiple media type and bandwidth requirement is being setup, ABNC cannot meet the need.

III. MULTIMEDIA SESSION SELECTION

The characteristics of a multimedia session are determined by the source and the destination access networks. A multimedia session consists of three media types: video, voice, and data. The problem of selecting the best connection becomes more complicated since a configuration or alternative may consist of one or more connections and the significance of each media type in communication quality must be considered. In this section, multimedia session attributes are described first. Then, the utility functions for media assignment are presented. Finally, the problem of multimedia session selection is formulated. Table I shows a summary of notations used in this section.

A. Multimedia Session Attributes

Multimode handsets came with multiple interfaces, which mean that a combination of different access networks can be exploited during communications. Given source handset S and correspondent handset C, A_i^S and A_j^C denote access networks of source handset and access networks of corresponding handset, respectively.

TABLE I. SUMMARY OF NOTATION FOR OUR PROBLEM FORMULATION

Symbol	Meaning
k	Transmission configuration identifier
C_k	The cost for a multimedia session with configuration k
P_k	The power consumption for a multimedia session with configuration k
SL_k	The security level for a multimedia session with configuration k
U_k	The utility for a multimedia session with configuration k
w_c, w_p, w_u, w_{sl}	Weight for criteria cost, power, quality, and security level, respectively

Let S_{ij} denote a connection established from source handset 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 destination. Due to the nature of multimedia session ABMNC considers more than one connection. We define k as a set of configurations that indicates how caller and callee are connected through their access networks. For example, 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.

Connections can be characterized by cost, power, security level, and utility, which are specified in the user profile.

- Cost: The cost information can be acquired from ISP. Charging depends on both source and destination networks, the cost is presented 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: The energy consumed per unit of time. It depends not only on the type of A_i^S but also on the number of interfaces used during a call.
- Security Level: Access networks implement different security mechanism and have different security levels. The security level of access network

without considering the application-level encryption mechanism follows the order of $SL(A_{UMTS}) > SL(A_{WiMAX}) > SL(A_{WiFi})$ [11]. The security level of a path is defined as the minimal security level of the access networks that consist of the path, $SL_k(S_{ij}) = \min\{SL(A_i^S), SL(A_j^C)\}$.

- Utility (quality): Although delay, packet loss rate of candidate connections and data rate allocation for each medium can be used to measure the quality of a multimedia session, we only consider the data rate as the quality index. The utility function U_k for configuration k will be defined in the next section.

The parameter cost, power, and security can be easily specified in the user profile but not the utility because the available bandwidth of each access network changes dynamically. In this study, it is assumed that each handset uses an IS service on Media Independent Handover (MIH) to report its available access networks and their respective available bandwidth [2] . Thus, with the assistance from IS, a handset can acquire all needed information for network selection.

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.

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 is defined as follows:

$$U_k^m = w_m \log_2(1 + \frac{X_m}{b_m}) \qquad (1)$$

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

In the ABMNC, the network connection problem is modeled as a simplified MKP. 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 the maximal utility value can be achieved without overflow. Thus, given N different paths, the media assignment problem of ABMNC is defined as follows.

$$\begin{aligned} U_k &= \max_{X_m} \sum_{i=1}^{N} \sum_m U_k^m x_{im} \\ &= \max_{X_m} \sum_{i=1}^{N} \sum_m w_m \log_2(1 + \frac{X_m}{b_m}) x_{im} \\ s.t. & \sum_m X_m x_{im} \le W_i , \\ & \sum_{i=1}^{N} x_{im} = 1,\ x_{im} \in \{0,1\}, \\ & \sum_m w_m = 1, \\ & T_m \le \frac{X_m}{b_m} \le 1 \end{aligned} \qquad (2)$$

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} type of media object assigned to the i^{th} path, U_k^m represents the utility value of media *m*, which depends on its weight w_m and allocated bandwidth X_m with respect to its required bandwidth b_m .

The first constraint ensures that the total allocated bandwidth to path *i* will not exceed its limit (knapsack weight) W_i , the available bandwidth of path *i*. The second one indicates 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.

C. *Problem Formulation*

Given a pair of communicating parties, each is equipped with n interfaces. Then, there exist n^2 possible network connections between them. A multimedia session contains three medium sessions: video, voice, and data session, 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 connection when the connection has sufficient bandwidth. With this assumption, there exist $(n^2)^3 = n^6$ possible transmission configurations. So, the problem of ABMNC is to choose the best configuration from the large number of possible configurations.

Based on the previous analysis of session attributes, choosing the best configuration belongs to a MADM problem and can be defined as follows.

$$\begin{aligned} S^* = \arg_k \ \max(w_c C_k + w_p P_k + w_u U_k + w_{sl} SL_k \\ s.t. CB > T_B \ and \ CS < T_S \end{aligned} \qquad (3)$$

where S^* is the best configuration obtained by comparison between score of *k*, which is the addition of the normalized contribution from each criterion multiplied by the weight factors. Let CB be the set whose elements are adequate when they are bigger than a threshold T_B , e.g., bandwidth. Let

CS be the set whose elements are adequate when they are smaller than a threshold T_S such as delay.

The MADM decision hierarchy for ABMNC can be shown in Fig. 1. The goal of the hierarchy is to select the most suitable configuration k for transmission at the top level. Solution alternatives are located at the bottom nodes. Video, voice and data are represented as v , s , and d , respectively.

IV. ABMNC

Applying a simple MADM solution to our problem is not feasible because we have to compare a large number of alternatives, which makes it impractical for real time applications. In the proposed scheme, the original hierarchy is decomposed into three iterated sub-MADM hierarchies and a hybrid scheme of SAW and AHP is used to efficiently solve the problem. AHP is used to decide the relative importance of criteria and media, which is then used by SAW for scoring. In the hybrid SAW and AHP scheme, each sub-MADM rates the path alternatives by considering all criteria except utility to produce a partial score first. Then, the overall score of a configuration is computed by merging the utility value after each media type is assigned.

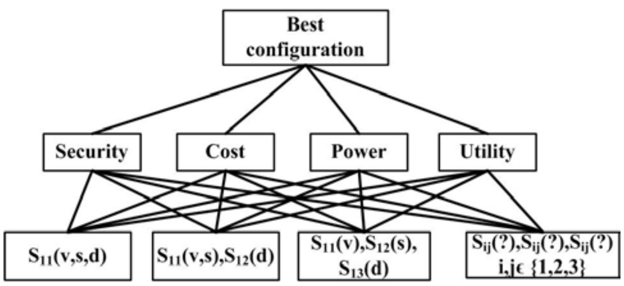

Figure 1. MADM hierarchy

The MADM hierarchy is divided into the single-path sub-MADM hierarchy that takes one path as input, the dual-path sub-MADM hierarchy that takes two paths, and the tri-path sub-MADM hierarchy that takes three paths. The single-path Sub-MADM hierarchy outputs its best configuration as an input to dual-path Sub-MADM. The dual-path Sub-MADM tries to find a better result by combining the input best single path with another path. Similarly, the tri-path Sub-MADM tries to find an optimal configuration that has three paths by integrating the best dual path from the dual-path Sub-MADM and another candidate path. Fig.2 shows single-path sub-MADM hierarchy.

A. AHP Weighting

In this study, AHP is used because it is easy to understand and does not need too much calculation. Furthermore, AHP is very convenient to establish a mathematical model [12]. AHP can be summarized as the process of constructing a problem as a hierarchy with a large number of attributes. The first step of AHP is to construct a decision hierarchy as shown in Fig.1. Then, pair-wise comparison between alternatives for each attribute in each hierarchy is done.

Since our approach deals with multiple media sessions, AHP must not only weight criteria or attributes w_c, w_p, w_{sl}, and w_u of our MADM hierarchy, but also weight media $w_m \mid m \in \{video, voice, data\}$ that is used during media assignment. Normally, attribute weights are decided according to user's preferences and AHP illustrates how important each attribute is by determining the relative weights of the compared attributes.

B. SAW

SAW is a simple and most often used multiple attribute decision technique. The method is based on the weighted average. In our research, the overall score of an alternative is computed as the weighted sum of all the attribute values. SAW classifies criteria into two categories, beneficial and non-beneficial. A criterion is beneficial if users are interested in having a higher value of it, e.g., security and utility; otherwise it is non-beneficial, e.g., cost and power.

In our study, the parameters used for different access technologies are derived as follows: 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 as shown in Table III.

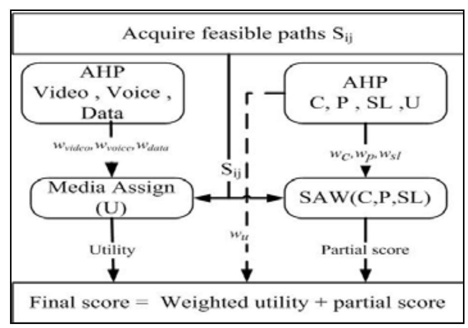

Figure 2. Single-path sub-MADM hierarchy

The scale values of 1-9 with calibration is used where 1 stands for extremely low while 9 represents extremely high. Table II shows the scale values, which are assigned to power and security.

V. ABMNC EXAMPLE

In this section, a simple example is shown to illustrate how ABMNC works.

A. Single-path

In the example, the source and the corresponding handset each have three interfaces, UMTS, WiMAX, and Wi-Fi. Thus, there exist 9 candidate network connections for the single-path sub-MADM hierarchy as shown in Table V.

First, AHP is used to elicit the weight for media (w_m) as shown in Table IV. The voice row shows that voice is twice as important as video, three times as important as data, and equal to itself. The video row shows that the video is twice as important as data. The matrix satisfies the transitive condition. The Consistency Ratio (CR) is applied to prove the matrix is consistency. [13] explains that when the CR of the comparison matrix is less than 0.1, a precise result can be achieved. Since our CR is equal to 0.0079, it is far below 0.1 so the matrix is consistent. A comparison matrix is also evaluated using Arithmetic Mean of the Normalized Column Vectors (AMNCV). AMNCV is defined as follows:

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

TABLE II. SCALE VALUES OF 1-9

Value	Definition
1	Extremely low
3	low
5	average
7	high
9	Extremely high
2,4,6,8	Middle value between elements

TABLE III. PARAMETERS SETTING

		Caller	Callee
Power	UMTS	420mins	Irrelevant
	WiMAX	180mins	Irrelevant
	Wi-Fi	210mins	Irrelevant
Security	UMTS	Middle	
	WiMAX	High	
	Wi-Fi	Low	
Cost	UMTS	0.0003$/s	0.0005$/s
	WiMAX	0.0005$/s	0.0003$/s
	Wi-Fi	0.0001$/s	0.0002$/s

TABLE IV. 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

Given $w_1 = w_{video}$, $w_2 = w_{voice}$, and $w_3 = w_{data}$, a_{ij} denotes an element in the comparison matrix. The media weight w_m acquired by (4) is $w_{video} = 0.297$, $w_{voice} = 0.539$, and $w_{data} = 0.164$. By a similar process, we can readily obtain weights for criteria w_c = 0.36, w_p = 0.05, w_{sl} = 0.05, and w_u = 0.54.

Second, SAW is used to construct a decision matrix based on parameters and scale values, where criteria considered are cost, power, and security level. In the un-normalized decision matrix, v_{ij} represents the original score of the j^{th} criterion of the i^{th} alternative. Table V shows the scores of all alternative paths in the un-normalized decision matrix.

Third, v_{ij} must be normalized to r_{ij} , the higher the r_{ij} , the better the alternative performs with respect to the j^{th} criterion. Beneficial criterion is normalized by using (5) while Non-beneficial criterion is normalized by using (6).

$$r_{ij} = \frac{v_{ij}}{\max_i (v_{ij})} \tag{5}$$

$$r_{ij} = \frac{\min_i (v_{ij})}{v_{ij}} \tag{6}$$

Finally, the best configuration is obtained by comparing the weighted average of all alternatives from normalized decision matrix by using (7).

$$MAX \sum_{j=1}^{m} w_j r_{ij} \tag{7}$$

where M denotes the number of criteria and w_j is the weight of the j^{th} criterion. We assume $w_c = w_{j=1}$, $w_p = w_{j=2}$, and $w_{sl} = w_{j=3}$. By applying (7), we get Table VI, which shows the partial scores of alternatives without utility criterion.

It can be seen from Table VI that the best alternative is S_{33} (WiFi-WiFi). Intuitively, S_{33} is the right choice since the selection seems cost-preferred without taking utility into consideration. Assume the bandwidth of S_{33} is 90Kbps, the media assignment scheme will allocate 64 Kbps, 16 Kbps, and 10 Kbps to video, voice, and data, respectively. By applying (2), we get the utility of video U_k^{video} 0.067, U_k^{voice} 0.161 and U_k^{data} 0.083. Thus, the total utility score U_k is equal to 0.311 and the final score of S_{33} is equal to 0.588 .

TABLE V. UN-NORMALIZED AND NORMALIZED DECISION MATRIX WITH RESPECT TO CRITERIA COST, POWER, AND SECURITY LEVEL

Decision matrix		UN-Normalized			Normalized		
Beneficial:1/Non-Beneficial:0		0	0	1	0	0	1
The weight of criteria		0.36	0.05	0.05	0.36	0.05	0.05
Alternatives / Criteria		*Cost*	*Power*	*Security*	*Cost*	*Power*	*Security*
UMTS-UMTS	S_{11}	0.0008	3	8	0.38	1.00	0.89
UMTS-WiMAX	S_{12}	0.0006	3	8	0.50	1.00	0.89
UMTS-WiFi	S_{13}	0.0005	3	7	0.60	1.00	0.78
WiMAX-UMTS	S_{21}	0.0010	7	8	0.30	0.43	0.89
WiMAX-WiMAX	S_{22}	0.0008	7	9	0.38	0.43	1.00
WiMAX-WiFi	S_{23}	0.0007	7	7	0.43	0.43	0.78
WiFi-UMTS	S_{31}	0.0006	6	7	0.50	0.50	0.78
WiFi-WiMAX	S_{32}	0.0004	6	7	0.75	0.50	0.78
WiFi-WiFi	S_{33}	0.0003	6	7	1.00	0.50	0.78

TABLE VI. PARTIAL SCORE FOR SINGLE-PATH

S_{11}	S_{12}	S_{13}	S_{21}	S_{22}	S_{23}	S_{31}	S_{32}	S_{33}
0.23	0.28	0.31	0.18	0.21	0.22	0.24	0.33	0.42

B. *Dual-path*

In dual-path, a large number of possible configurations is considered. The output of the single-path sub-MADM S_{33} is input to the dual-path sub-MADM, which tries to find the best result by combining S_{33} with another path in order to reduce the complexity.

When considering a dual-path alternative, the normalized scores of all v_{ij} must be reevaluated, because the computed results will be changed if $\max_i(v_{ij})$ and $\min_i(v_{ij})$ change. Fortunately, the v_{ij} with respect to all criteria except utility will become smaller for beneficial criteria and larger for non-beneficial criteria if more paths are involved. Thus, when we insert a new dual-path configuration by adding single-path to an existing single-path alternative, $\max_i(v_{ij})$ and $\min_i(v_{ij})$ remain the same when utility is not considered. Therefore, Table V remains unchanged.

When the same computations are applied on the dual-path configuration, the partial score of $k_2 = \{S_{32}, S_{33}\}$ can be derived as 0.243, which is smaller than $k_1 = \{S_{33}\}$. The partial scores for dual-path are shown in Table VII.

TABLE VII. PARTIAL SCORE FOR DUAL-PATH

S32,S33	S31,S33	S23 ,S33	S11,S33
0.243	0.209	0.184	0.175

We assume the bandwidth of S_{32} is 90Kbps. Then, the media assignment scheme will assign 64 Kbps, 64 Kbps, and 20 Kbps to video, voice, and data , respectively to S_{33} and S_{32}. By applying (2), the utility of video U_k^{video}, voice U_k^{voice} and data U_k^{data} can be readily obtained as 0.067, 0.5, and 0.147 ,respectively. The total utility score U_k equals to 0.714. Finally, the final score of $k_2 = \{S_{32}, S_{33}\}$ is derived to be equal to 0.629, which is larger than S_{33}. So the best configuration is $S^* = (S_{32}, S_{33})$ by the dual-path sub-MADM. The triple-path sub-MADM, in this case, cannot find a better configuration and hence ABMNC returns configuration $S^* = (S_{32}, S_{33})$ as the best connection.

VI. CONCLUSION

Multimedia communication has become part of daily live for many people. Therefore, how to choose an appropriate configuration for a multimedia session between multimode handsets is an important issue. In this paper, a new paradigm called ABMNC is presented to address this issue. Unlike traditional network selection problems, ABMNC is modeled as a MADM problem along with media assignment. To reduce the size of candidate solutions, the ABMNC MADM hierarchy is divided to three Sub-MADMs and an efficient hybrid SAW and AHP scheme was proposed to solve the problem. An example has been illustrated to show how our presented approach works.

This paper only considered bandwidth as a quality index. In the future, we will consider more types of QoS parameters like packet loss rate, delay, etc., to make ABMNC more practical. Also, each criterion in connection evaluation may be correlated. For example, a larger bandwidth may also cost more. So, we will use different MADM model other than AHP in our future study.

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