Network Selection in Heterogeneous Wireless Environment: A Ranking Algorithm

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***Abstract*—Vertical Handoff decision algorithms facilitate the terminal to be connected to the network which suffice the requirements of the application. It ushers the terminal to be connected to the most optimum network amongst those in the purview of the mobile terminal. The selection criterion involves multiple attributes. Although many ranking algorithms have been proposed, there is a need to lay a stress on the user requirements and the terminal power consumption. In this paper we propose a ranking algorithm keeping in view the user preferences and the application priorities. Having a close proximity with TOPSIS algorithm, the idea proposed overcomes the ranking abnormalities and scores high on efficiency.**

I. INTRODUCTION

4G technologies are at the verge of making its own way to usher the research community to provide optimum access of network with the availability of very high data rates and efficient way of transmission. Also the increase in access of technologies like WLAN, Bluetooth, 3GPP cellular networks etc would make heterogeneous IP infrastructure the future of communication. Evolution of value added services and easy network access at any point of time creates a responsibility on the part of network provider to see to that the terminal has the access to the most optimum network at any point of time. Service Level Agreements (SLA's) amongst the network providers have further created a demand for a selection mechanism amongst those available.

Traditional handoff decision algorithm (Horizontal hand off decision algorithms) where the terminal used to switch to that mobile base station having a high signal strength are unable to meet the requirements of the emerging technologies and the multimodal devices. These devices have created a new requirement where the user has access to multiple interfaces for each application and also can select and switch to any of the available based on the application requirements, the interface capacities and the constraints of the mobile terminal. Thus the terminal has the facility of using multiple interfaces simultaneously which exists at that particular moment. This new need has compelled the service provider to avert form the traditional algorithms and move to Vertical Handoff Decision Algorithms. This intelligent handoff algorithm provides access to the most optimum network in the region of overlay networks. Thus the user need not bear the extra cost and so does the network provider the extra burden on his/her part.

Quality of Service (QOS) requirements factors play a crucial role in selection process. Since the decision is based on multiple criteria and the importance of each of these may vary according to the requirement of the user, this has been reduced to the problem of multi attribute decision making (MADM) with the presence of a weight matrix. Several MADM algorithms have been proposed namely TOPSIS, SAW, AHP, GRE but many of these suffer from ranking abnormalities. Hence a ranking algorithm which can remove these abnormalities and can score high on efficiency is required. In the next section we proceed to look at the related work. The subsequent section defines the variables. Later we explain in brief the algorithm; and in the last section we discuss about the results obtained.

II. RELATED WORK

Janise and Fang [1] describe in brief the evolution of 4G and vertical handoff process throwing a light on policy decision and the context transfer. Farooq Bari and Victor Leung [2] proposed a new model based on network selection approach. The additional nodes proposed in the paper i.e., the authentication node, service announcement and data collection node facilitate better sharing of information among the home network and other networks thus providing better service delivery over the network.

Wenhui Zhang [3] gives a description of fuzzy approach for network selection process and also compares it with the application of SAW and TOPSIS approaches. Balasubramaniam et al. [11] also use the AHP method in their decision making process. Tansir Ahmed, Kyandoghere Kyamakya and Markus Ludwig in [8] propose a new an innovative way for network selection based on AHP.

Farooq Bari and Victor Leung in [6] and [7] clearly describe the TOPSIS process and its application in network selection. In [6] the authors show how both compensatory and non-compensatory decision algorithms based on MADM ease the process of ranking. In [7] iterative TOPSIS is defined keeping in the view the ranking abnormalities of MADM approaches and illustrated with an example.

Enrique, Navarro and Vincent in [8] compare and contrast the available MADM approaches. Enrique, Navarro, Wong and YuxiaLin in [9] propose a model based on Markov decision process .The model makes use of probability and introduces to link reward function.

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III. DECISION MAKING CRITERIA

The attributes used for the selection algorithm use the same criteria that have been used in [5] for TOPSIS procedure. However there was a need felt for considering another criteria for the selection process. The attributes used are below.

Cost Per Byte: This the amount charged by the network operator to which the user is subscribed or the operator whose services are in use. (Includes the roaming arrangements).

Total Bandwidth: It is the overall bandwidth available over the link accessed by the mobile terminal. It is measured in terms of bps (bits per second).

Available Bandwidth: This is the measure of per user bandwidth allotted by the network operator which is dynamic and can change as per the utilization of the network. It is measured in terms of bps (bits per second).

Delay: The packet delay gives the measure in milliseconds of the average delay for the packet on the wireless link.

Jitter: It is the delay variations (average) on the wireless link of the network. It is measured in milliseconds.

Packet Loss: It is the measure of average packet loss between the mobile terminal and the network operator. It is measured for every 1 million packets sent.

Signal Strength: It is the measure of signal strength available to the mobile terminal from the base station of the network. This was the basis of traditional handoff procedures. It is measured in terms of dB-micro volts per meter (dBμV/m)

Utilization: It is the percentage of utilization of the wireless link of the network used.

Terminal Power Consumption is one of the vital criteria to be considered for access of the network. For a mobile terminal having a low battery power, the optimum network must not only satisfy the QOS factors but also should give due importance to the battery power available at that point of time. For a mobile with low batter power, the network with high signal strength, moderate quality and cost may prove to be more efficient than the network with best quality, low cost but low signal strength.

IV. THE PROCESS

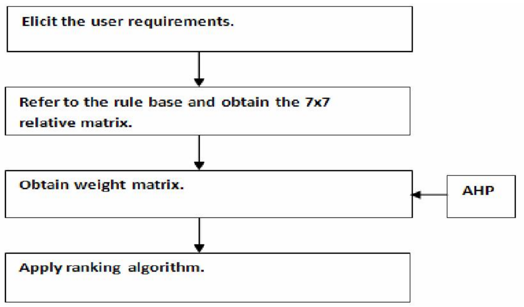

Fig 1: Process flow of the algorithm

A. *First Phase:*

In this phase the available networks are short listed based on the applications they support for the mobile terminal i.e., the type of application (real time application, data services etc) and the signal strength of the network. Since the data rate for each application varies, it is essential to consider only those networks for the second phase which have substantial data rates that can support the type of application. Also, as the battery power and the processor speed play an important role for the network to be selected they are compared with the signal available networks at that moment to eliminate those from consideration which are far less compatible with the terminal power consumption

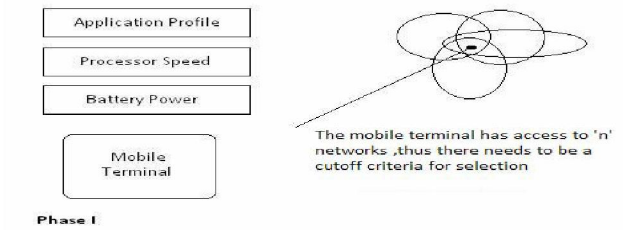

Fig 2: Elimination Phase for the networks.

The application profile contains the type of application, the requirements of the application and the battery power gives the current capacity of the terminal in terms of power usage and can be used to set the cut off limit for signal strengths (in fact we set the lower bound based on the battery power at the moment of the terminal and also under the assumption that maximum battery power will be used).

B. *Second Phase:*

It consists mainly of two steps

(i) Obtain the weight matrix

(ii) Apply the ranking algorithm.

1) *Obtaining the weight matrix:* The total seven variables (AB TB U C D L J) are classified under three categories speed, cost and quality which are easily understood by the user. The user then gives the input for the three variables for each application in terms of linguistic variables (each variable having a value assigned to it) (Table given below)

TABLE I

LINGUISTIC VARIABLES WITH THEIR VALUES

Linguistic variable	Value assigned
Very high	9
High	7
Medium	5
Low	3
Very low	1

The user is allowed to specify the priority as between two of the adjacent linguistic variables given.

Then we have a set of heuristics predetermined by requirement analysis of resources for each application which give the relative priority between the two sets (AB, TB, U) and (D, L, J).These sets of heuristics are to be maintained for each application .Then the values of variables are obtained by multiplying user input and the ratio obtained from the heuristics. With these values a 7x7 relative matrix is made and then the eigen values and vectors are computed. Now the eigen vector corresponding to the largest eigen value is taken and normalized. Then the transpose of that eigen vector is taken and then converted into a diagonal matrix. This matrix is our weight matrix.

$$RM = \begin{bmatrix} ab/ab & tb/ab & u/ab & c/ab & d/ab & l/ab & j/ab \\ ab/tb & tb/tb & u/tb & c/tb & d/tb & l/tb & j/tb \\ ab/u & tb/u & u/u & c/u & d/u & l/u & j/u \\ ab/c & tb/c & u/c & c/c & d/c & l/c & j/c \\ ab/d & tb/d & u/d & c/d & d/d & l/d & j/d \\ ab/l & tb/l & u/l & c/l & d/l & l/l & j/l \\ ab/j & tb/j & u/j & c/j & d/j & l/j & j/j \end{bmatrix}$$

Where RM=relative matrix; ab, tb, u, c, d, l, j are the values of AB TB U D L J respectively.

$$\text{Eigen Values of RM} = \begin{bmatrix} ev1 \\ ev2 \\ ev3 \\ . \\ . \\ . \\ ev7 \end{bmatrix} \quad \text{Weight matrix} = \begin{bmatrix} ev1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & ev2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & ev3 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & ev4 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & ev5 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & ev6 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & ev7 \end{bmatrix}$$

When two attributes are compared they would be given values from the following table.

Score	Rule
1	Equal preference to both
3	One is moderately preferred over other
5	One is strongly preferred over the other
7	Very strong preference over the other
9	Extreme preference over the other

2) *The ranking algorithm*:

i. Obtain the weight vector as described above and thus get the diagonal weight matrix.

$$W = \begin{bmatrix} w_{TB} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & w_{AB} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & w_U & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & w_C & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & w_D & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & w_J & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & w_L \end{bmatrix}$$

ii. From the networks within the reach of the mobile terminal (after phase 1) obtain the decision matrix.

$$D = \begin{bmatrix} TB_1 & AB_1 & U_1 & C_1 & D_1 & J_1 & L_1 \\ TB_2 & AB_2 & U_2 & C_2 & D_2 & J_2 & L_2 \\ TB_3 & AB_3 & U_3 & C_3 & D_3 & J_3 & L_3 \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ TB_n & AB_n & U_n & C_n & D_n & J_n & L_n \end{bmatrix}$$

iii. Normalize the decision matrix.

$$D = \begin{bmatrix} (TB_{norm})_1 & (AB_{norm})_1 & (U_{norm})_1 & (C_{norm})_1 & (D_{norm})_1 & (J_{norm})_1 & (L_{norm})_1 \\ (TB_{norm})_2 & (AB_{norm})_2 & (U_{norm})_2 & (C_{norm})_2 & (D_{norm})_2 & (J_{norm})_2 & (L_{norm})_2 \\ (TB_{norm})_3 & (AB_{norm})_3 & (U_{norm})_3 & (C_{norm})_3 & (D_{norm})_3 & (J_{norm})_3 & (L_{norm})_3 \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ (TB_{norm})_n & (AB_{norm})_n & (U_{norm})_n & (C_{norm})_n & (D_{norm})_n & (J_{norm})_n & (L_{norm})_n \end{bmatrix}$$

iv. Obtain the weighted normalize decision matrix.

$$WN = W * D$$

$$WN = \begin{bmatrix} (TB_{wn})_1 & (AB_{wn})_1 & (U_{wn})_1 & (C_{wn})_1 & (D_{wn})_1 & (J_{wn})_1 & (L_{wn})_1 \\ (TB_{wn})_2 & (AB_{wn})_2 & (U_{wn})_2 & (C_{wn})_2 & (D_{wn})_2 & (J_{wn})_2 & (L_{wn})_2 \\ (TB_{wn})_3 & (AB_{wn})_3 & (U_{wn})_3 & (C_{wn})_3 & (D_{wn})_3 & (J_{wn})_3 & (L_{wn})_3 \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ (TB_{wn})_n & (AB_{wn})_n & (U_{wn})_n & (C_{wn})_n & (D_{wn})_n & (J_{wn})_n & (L_{wn})_n \end{bmatrix}$$

v. Obtain the median vector by finding the median of each of the column in the normalized weighted decision matrix.

$$M = \begin{bmatrix} M_{TB} & M_{AB} & M_U & M_C & M_D & M_J & M_L \end{bmatrix}$$

vi. Now, obtain the delta matrix as defined in the following way.

$$\Delta_{WN} = \begin{bmatrix} (TB_{wn})_1 - M_{TB} & (AB_{wn})_1 - M_{AB} & M_U - (U_{wn})_1 & M_C - (C_{wn})_1 & M_D - (D_{wn})_1 & M_J - (J_{wn})_1 & M_L - (L_{wn})_1 \\ (TB_{wn})_2 - M_{TB} & (AB_{wn})_2 - M_{AB} & M_U - (U_{wn})_2 & M_C - (C_{wn})_2 & M_D - (D_{wn})_2 & M_J - (J_{wn})_2 & M_L - (L_{wn})_2 \\ (TB_{wn})_3 - M_{TB} & (AB_{wn})_3 - M_{AB} & M_U - (U_{wn})_3 & M_C - (C_{wn})_3 & M_D - (D_{wn})_3 & M_J - (J_{wn})_3 & M_L - (L_{wn})_3 \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ (TB_{wn})_n - M_{TB} & (AB_{wn})_n - M_{AB} & M_U - (U_{wn})_n & M_C - (C_{wn})_n & M_D - (D_{wn})_n & M_J - (J_{wn})_n & M_L - (L_{wn})_n \end{bmatrix}$$

$$\Delta = \begin{bmatrix} (\Delta_{TB})_1 & (\Delta_{AB})_1 & (\Delta_U)_1 & (\Delta_C)_1 & (\Delta_D)_1 & (\Delta_J)_1 & (\Delta_L)_1 \\ (\Delta_{TB})_2 & (\Delta_{AB})_2 & (\Delta_U)_2 & (\Delta_C)_2 & (\Delta_D)_2 & (\Delta_J)_2 & (\Delta_L)_2 \\ (\Delta_{TB})_3 & (\Delta_{AB})_3 & (\Delta_U)_3 & (\Delta_C)_3 & (\Delta_D)_3 & (\Delta_J)_3 & (\Delta_L)_3 \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ (\Delta_{TB})_n & (\Delta_{AB})_n & (\Delta_U)_n & (\Delta_C)_n & (\Delta_D)_n & (\Delta_J)_n & (\Delta_L)_n \end{bmatrix}$$

vii. Obtain the resultant matrix for consideration of ranks by summing up the values of the row elements.

$$R = \begin{bmatrix} (\Delta_{TB})_1 + (\Delta_{AB})_1 + (\Delta_U)_1 + (\Delta_C)_1 + (\Delta_D)_1 + (\Delta_J)_1 + (\Delta_L)_1 \\ (\Delta_{TB})_2 + (\Delta_{AB})_2 + (\Delta_U)_2 + (\Delta_C)_2 + (\Delta_D)_2 + (\Delta_J)_2 + (\Delta_L)_2 \\ (\Delta_{TB})_3 + (\Delta_{AB})_3 + (\Delta_U)_3 + (\Delta_C)_3 + (\Delta_D)_3 + (\Delta_J)_3 + (\Delta_L)_3 \\ . \\ . \\ . \\ (\Delta_{TB})_n + (\Delta_{AB})_n + (\Delta_U)_n + (\Delta_C)_n + (\Delta_D)_n + (\Delta_J)_n + (\Delta_L)_n \end{bmatrix}$$

The values of resultant matrix arranged in decreasing order give the resultant ranks of the networks.

V. Simulation and Results

In order to analyse the algorithm and the effectiveness we have taken 5 networks [6] with the attributes values as given. The results and ranks are as depicted in the following figure.

The decision matrix (DM) is

DM =

	AB (mbps)	TB (mbps)	U (%)	C (%)	D (ms)	L (ms)	J(per 10^6)
Network1 UMTS	0.2	2	10	100	400	50	100
Network2 802.11b	1	11	20	20	200	25	20
Network3 802.11a	2	54	20	10	100	15	15
Network4 802.11n	5	100	40	5	150	30	20
Network5 4G	5	100	20	30	100	20	15

$$Weightmatrix = \begin{bmatrix} 0.0274 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.0196 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.0152 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.1918 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.3197 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.1066 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.3197 \end{bmatrix}$$

The ranks of the networks are

Ntwk#1	Ntwk#2	Ntwk#3	Ntwk#4	Ntwk#5
-0.5974 Rank-5	-0.0429 Rank-4	0.0811 Rank-1	0.0297 Rank-3	0.0536 Rank-2

This method has also been tested and found not to have the drawback of TOPSIS when the process is done iteratively.

No. of iterations	P - Ntwk#1	P - Ntwk#2	P - Ntwk#3	P - Ntwk#4	P - Ntwk#5
1	-0.5974 Rank-5	-0.0429 Rank-4	0.0811 Rank-1	0.0297 Rank-3	0.0536 Rank-2
2	------------	-0.1558 Rank-4	0.0850 Rank-1	-0.0145 Rank-3	-0.0119 Rank-2
3	------------	------------	-0.0027 Rank-1	-0.1359 Rank-3	-0.1198 Rank-2
4	------------	------------	0.0603 Rank-1	------------	-0.0603 Rank-2

MADM algorithm is said to be ideal if the removal of the bottom ranked candidate does not alter the ranking. However, TOPSIS algorithm did not meet this requirement and so iterative TOPSIS was proposed in [5].

For each of the attributes namely Cost, Delay, Jitter, Loss and utilization the affect of removal of bottom ranked network will either increase or decrease the median. In either of the cases the difference (Median – Attribute value of weighted normalized matrix) would vary respectively. However as we subtract from a common term the order for the each of column will remain the same (in the delta matrix). The same would be the case in case of the attributes Total bandwidth and available bandwidth (where the delta matrix attribute being Attribute value of weighted normalized matrix– median). Now, as the order of each of the column does not change the value in the rank matrix will also not change since it is the summation of the row elements. Thus the ranking will remain the same. Hence, the algorithm is consistent.

VI. Conclusion

MADM algorithms are very well known and have been applied in many research areas. Coming to the application of these algorithms for network selection, it has been found that TOPSIS is one of the most preferred one compared to others. It is proved that TOPSIS can change when a candidate at the bottom of the ranking is removed from the comparison, and the iterative approach gives a more consistent and accurate final result. Terminal Power Consumption and User preferences are not given due importance of the available procedures. The algorithm proposed overcomes the above abnormalities and scores high on efficiency by consuming less memory and at an optimum processor speed.

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