Weight Influence of Logarithmic and Exponential Functions on the Selection of Wireless Networks Using Multi-Criteria Decision-Making Methods

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Abstract—This research aims to study the influence of logarithmic and exponential functions on the multi-criteria decision-making algorithm that changes the linear to the nonlinear method. It is carried out to better understand the multi-criteria decision-making (TOPSIS) algorithm whereby these functions may influence the criteria weights during the selection of the best network. The experiment is applied under different network types to evaluate the most optimum network that leads to better throughput, low latency, minimum BER, and low price per MB. The algorithms are assessed in MATLAB simulation environments. In addition, the adoption of the Wi-Fi networks standard is determined by factors such as bandwidth, signal to noise ratio and the channel modulation technique during the decision-making process. The simulation results showed that the exponential function had produced approximately similar results to that of linear TOPSIS algorithm because both keep the weights to demonstrate positive values. However, logarithmic TOPSIS produced different results and a worst-case scenario, as the weights have negative values which lead to a phase shift of 180° during the decision process. Thus, linear TOPSIS was found to have the best results while logarithmic TOPSIS had the worst outcome.

Keywords—multi criteria decision making, AHP, TOPSIS

1 Introduction

In most nations, consumer interest in mobile services is increasing because of the need for data access anywhere at all times. Moreover, the rise in communication infrastructures offers connectivity through wired and unwired technologies [1]. As such, network providers face issues in supporting users or enhancing the infrastructure. Different wireless network technologies are being implemented into the network to provide a smooth integration, and interoperability [2]. The aim of this paper is to pick the optimum candidate network in a distinct wireless environment. The study is done with three unique algorithms that factors in throughput, latency, BER and cost per Mb [3]. These factors affect the various networks during the selection phase, the multi-criteria decision-making (MCDM) algorithm exponential and logarithm functions, changing the linear to the nonlinear method. The paper starts with the theoretical background presented in Section 2. The simulation and setup are introduced in Section 3, and the results and discussion are described in Section 4. Finally, Section 5 concludes our work.

2 Theoretical background

The MCDM techniques are employed for their decision-making capabilities used to choose the network nearest to the optimum standard and not the poorest one [4]. Numerous studies were done in the selection phase with a standard MCDM method called the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) technique to successfully deal with the handover decision-making process. Works in [5] [6] suggested a TOPSIS technique that factors in the price, total bandwidth, network usage, lag and interruptions. A separate study in [7] [8] proposed the formation and arrangement of the decision matrix using different parameters. According to [9] [10], the TOPSIS technique lowers limited connectivity in mixed networks lowering the handovers and packet loss while increasing the average user throughput [11]. However, the predetermined value utilized for weighing the handover metrics may have minor flaws, because of the diversity in signal power resulting from user movement in dynamic situations [12].

2.1 Network performance parameters

The criteria used in the selection algorithm are assessed by the TOPSIS algorithm, include throughput, latency, bit error rate (BER) and price per Mb. We will explain the Signal-to-Noise Ratio (SNR) and bandwidth (B) that effects each criterion used in our research [13]. The noise power is calculated using the transmission signal bandwidth and the n(t) spectral characteristics, where n(t) is a white gaussian random noise with a zero mean and a power density of $N_0/2$. The noise power in bandwidth 2B is defined by equation (1). Where, N_0 is the noise power [14]. The SNR of the received signal can be given by equation (2), and P_r is received power. SNR is usually defined as a function of the signal energy per bit E_b or per symbol Es as in equation (3), T_s is the symbol time while T_b is time of the bit.

$$N = \frac{N_0 \times 2B}{2} = N_0 B \tag{1}$$

$$SNR = \frac{P_r}{(N_0 B)} \tag{2}$$

$$SNR = \frac{P_r}{(N_0 B)} = \frac{E_S}{(N_0 B T_S)} = \frac{E_b}{(N_0 B T_b)} \tag{3}$$

For average power S constraints, Shannon channel capacity with a channel-side information (CSI) receiver can be gained as described in the equation = $S/(N_0B)$. The efficiency of Shannon is equivalent to the power of Shannon of AWGN noise with throughput = B log2(1 + SNR) and is distributed over SNR. Therefore, the capacity of Shannon is also known as the capacity of Ergodic [15] [16]. Considering a discrete-time AWGN channel having the relationship between bandwidth and power, the signal-to-noise ratio is constant and defined by (4) [17].

$$SNR = S/(N_0 B) \tag{4}$$

Throughput. Shannon's equation that C = B log2(1 + SNR) illustrates the capacity of interruption is applied to slowly varying channels where the SNR can be considered fixed over a large number of transmissions. After the burst, it changes value according to the fading criteria. In this model, if the communication channel has accepted a given SNR during a transmission, data can be sent through the communication channel at throughput as in equation (5) [18] [19]. The probability of outage declared by the transmitter is then by equation (6). The rate of the correctly received bits out of various transmission bursts can be given by equation (7) [20].

$$B \log2(1 + SNR) \tag{5}$$

$$P_{out} = P\,(SNR < SNR_{min}) \tag{6}$$

$$C_o = (1 - P_{out})\, B \log_2 (1 + SNR_{min}) \tag{7}$$

Latency. A QoS measure is packet latency from source to destination, such as video conferencing, gaming and Voice over Internet Protocol (VoIP) [21]. This parameter allows us to study packet queueing delays [22] that consists of four elements. First, the transmission delay (packet length/ throughput) is a function of packet length and network bandwidth (bps) [23]. Second, the delay of radio propagation is calculated by (distance/transmission speed) [24]. Third, the delay of queueing is defined by equation (8). Where N is the number of packets and L denotes the packet size.

$$\text{Average queuing delay} = \left(\frac{\frac{(N-1)}{L}}{2 * C} \right) \tag{8}$$

Fourth, the processing delay in high-speed routers, in the range of microseconds or less, making them insignificant. Therefore, the total delay relationship can be expressed mathematically as D = Transmission delay + Radio propagation delay + Average queuing delay [25].

Bit error rate. In communication systems, BER is a significant metric for assessing system performance. For example, in simple systems where the channel is simplified by the additive white gaussian noise (AWGN), the BER is found quickly [26]. The required power to keep a probability of error (P_b) small in fading channels is greater than in AWGN channels. The BER expression for M-QAM as in equation (9), where M is order of M-array and the SNR = Eb/No [27].

$$P_b = \frac{\sqrt{M} - 1}{\sqrt{M} \log_2 \sqrt{M}} \operatorname{erfc} \left(\sqrt{\frac{3(\log_2 M)\, E_b}{2(M-1)\, N_0}} \right) \tag{9}$$

Price per Mb. The price per 1Mb is equal to some values (\$), so the price increases when the throughput increases [28]. Therefore, it can get the price per Mb by equation (10).

$$\text{Price per Mb} = \frac{\text{price}}{1 \times 10^6} \times \text{Throughput.} \tag{10}$$

Packet length and packets size. Packet length is measured between network server and Internet connection. The central limit theorem may deduce that the aggregate traffic has a Gaussian distribution due to several devices generate the packets. Therefore, when data traffic flows through the aggregation point, it suffers a non-linear transformation, and the network servers group the packets (bytes) according to the adopted protocol (IP, ICMP, TCP or UDP), producing a non-uniform distribution for the packet size [29] [30].

The non-linear transformation of the Beta distribution gives the bimodal distribution [31]. For the ethernet network standard, the Maximum Traffic Unit (MTU) is 1500 bytes. The maximum packet length that can be sent through a network interface is 1492 bytes because eight bytes are used in the logical link control (LLC) header [32]. It can be good to only send one larger packet instead of multiple small ones [33]. The negative impact is that one big packet will take up space in the buffers, creating more packet loss if the buffer is not large enough to handle the incoming packets. The theoretical max size for TCP and UDP is around 64 kB (TCP 65535 bytes and UDP 65507 bytes) [34] because of the MTU (Maximum Transmission Unit), which is the largest size of data that can be sent at a time. If data with a size larger than the MTU is passed from the transport layer to the network layer, it will be fragmented into smaller packages provided with the IP header with the final destination address. The MTU size used for the simulation was one with packet size of 1000 bytes payload [35]. For all scenarios, real-time video is expected to be conveyed using RTP/UDP/IP packets.

The number of packets. The transmission generates packet losses during the transmission of digital video signals through a packet switching system. Therefore, the time required for the packet in transmission medium is Np = Number of packets, d = delay, then the size of the packet is Sp = d/Np. Figure 1 shows The header of the video signal transmitter, according to [36] [37].

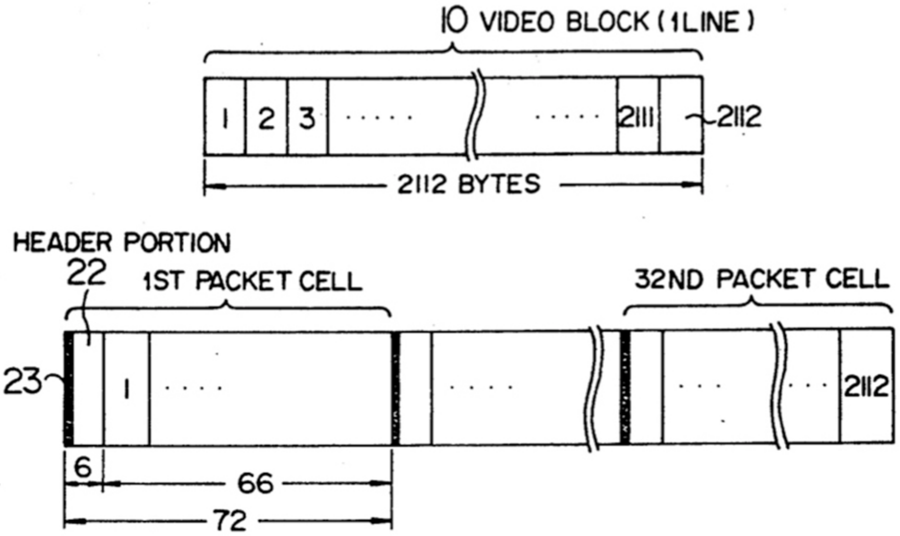

Fig. 1. The header of video signal transmitter

2.2 Analytic hierarchy process (AHP)

This method assesses the weight of different criteria of a candidate network [38] [39]. A pairwise comparison approach is used and entered into a matrix and used to determine a vector of priority weights [40]. Therefore, to calculate the pairwise defined by (11), where, $x_{ii} = 1$, and x_{ij} elements are obtained from Table 1, (Saaty table) for pairwise comparison technique.

$$\begin{bmatrix} x_{11}\, x_{12} \cdots\cdots\cdots x_{1n} \\ x_{21}\, x_{22} \cdots\cdots\cdots x_{2n} \\ x_{n1}\, x_{n2} \cdots\cdots\cdots x_{nn} \end{bmatrix} \tag{11}$$

Note that: W_i is a weight for attribute i, $i = 1$ to n, where n = number of attributes and $(x_{ij} = x_{i/x_j})$ the result of a pairwise comparison between attribute i as compared to attribute j as shown in Table 1. Therefore, the normalized as defined by (12), where, $r_{ij} = x_{ij} \Big/ \sum_{i=1}^{n} x_{ij}$, the weight can be calculated by equation (13), W_i the assigned weight for every parameter and that $\sum_{j=1}^{n} W_i = 1$ [41].

$$\begin{bmatrix} r_{11}\, r_{12} \cdots\cdots\cdots r_{1n} \\ r_{21}\, r_{22} \cdots\cdots\cdots r_{2n} \\ r_{n1}\, r_{n2} \cdots\cdots\cdots r_{nn} \end{bmatrix} \tag{12}$$

$$W_i = \frac{\sum_{j=1}^{n} r_{ij}}{n} \tag{13}$$

Table 1. Saaty scales for pairwise comparison technique

Saaty Scales	The Relative Importance of the Two Sub-Elements
1	Equally important.
3	Moderately important
5	Strongly important.
7	Very strong important.
9	Extremely important.
2,4,6,8	Intermediate value.

2.3 TOPSIS algorithm

The linear-TOPSIS algorithm is used to find the best solution for the system under different conditions for each metric [42] and [43]. The steps of the TOPSIS algorithm are:

- Construct the decision matrix (DM) as specified by (14), where network1 and network2 are two feasible options from which the decision-makers must choose, and C_1, C_2, C_3 and C_4. x_{ij} are the ratings of an alternative based on criteria [44].

$$DM = \begin{bmatrix} C_1 & C_2 & C_3 & C_4 \\ x_{11} & x_{12} & x_{13} & x_{14} \\ x_{21} & x_{22} & x_{23} & x_{24} \end{bmatrix} \tag{14}$$

- Construction of the Normalized Decision Matrix, as shown in the equation (15), where r_{ij} the normalization value, i = 1, 2, … m, and j = 1, 2, … n to convert the dimensional attributes into non-dimensional ,ones to compare between different attributes [45].
- Construct the Weighted Normalized Decision Matrix as in equations (16) and the effect of each function on the weight, where w_i is the weight of criterion r_{ij}.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} \\ r_{21} & r_{22} & r_{23} & r_{24} \end{bmatrix} \tag{15}$$

- First construct linear-TOPSIS.

$$v_{ij} = \begin{bmatrix} r_{11} \times w_1 & r_{12} \times w_2 & r_{13} \times w_3 & r_{14} \times w_4 \\ r_{21} \times w_1 & r_{22} \times w_2 & r_{23} \times w_3 & r_{24} \times w_4 \end{bmatrix} \tag{16}$$

- Second construct Exponential-TOPSIS by defined (17).

$$v_{ij} = \begin{bmatrix} r_{11} \times \mathrm{Exp}.w_1 & r_{12} \times \mathrm{Exp} \times w_2 & r_{13} \times \mathrm{Exp}.w_3 & r_{14} \times \mathrm{Exp} \times w_4 \\ r_{21} \times \mathrm{Exp}.w_1 & r_{22} \times \mathrm{Exp} \times w_2 & r_{23} \times \mathrm{Exp}.w_3 & r_{24} \times \mathrm{Exp} \times w_4 \end{bmatrix} \tag{17}$$

- Third construct Logarithmic-TOPSIS by defined (18).

$$v_{ij} = \begin{bmatrix} r_{11} \times \mathrm{Log} \times w_1 & r_{12} \times \mathrm{Log} \times w_2 & r_{13} \times \mathrm{Log} \times w_3 & r_{14} \times \mathrm{Log} \times w_4 \\ r_{21} \times \mathrm{Log} \times w_1 & r_{22} \times \mathrm{Log} \times w_2 & r_{23} \times \mathrm{Log} \times w_3 & r_{24} \times \mathrm{Log} \times w_4 \end{bmatrix} \tag{18}$$

- Determine Ideal and Negative-Ideal Solutions.

$A^+ = \{v_1^+, v_2^+, \ldots\ldots\}, v_j^+ = \max_i(v_{ij})$, associated with benefit or best criteria.
$A^- = \{v_1^-, v_2^-, \ldots\ldots\}, v_j^- = \min_i(v_{ij})$, associated with cost or worse criteria.

- Calculate the solution measure as shown in equations (19) and (20):

$$S_i^+ = \sqrt{\sum_{j=1}^{m} \left| v_i^+ - v_{ij} \right|}, \; i = 1, 2, \ldots m \text{ (positive-ideal-solution)} \tag{19}$$

$$S_i^- = \sqrt{\sum_{j=1}^{m} \left| v_i^- - v_{ij} \right|}, \; i = 1, 2, \ldots m \text{ (positive-ideal-solution)} \tag{20}$$

- Calculate the proportional proximity to the Ideal-solution C_i, like in equation (21). Where, $0 < C_i < 1$, {1, 2, … m}, $C_i = 1$ if $S_i = S^+$ also $C_i = 0$ if $S_i = S^-$

$$C_i = \frac{S_i^-}{S_i^+ + S_i^-} \tag{21}$$

3 Simulation and setup

The study demonstrates how weights and attributes influence the scoring values and efficiency functions of linear-TOPSIS algorithms, logarithmic and exponential algorithms. Varying parameters were tested and are illustrated in this section through MATLAB simulation. With regards to Table 2, we use three different Wi-Fi networks as the topology based on (IEEE) 802.11 standards. In addition, the SNR values, bandwidth, and M-QAM modulation techniques for all the Wi-Fi networks vary, as shown in Figure 2.

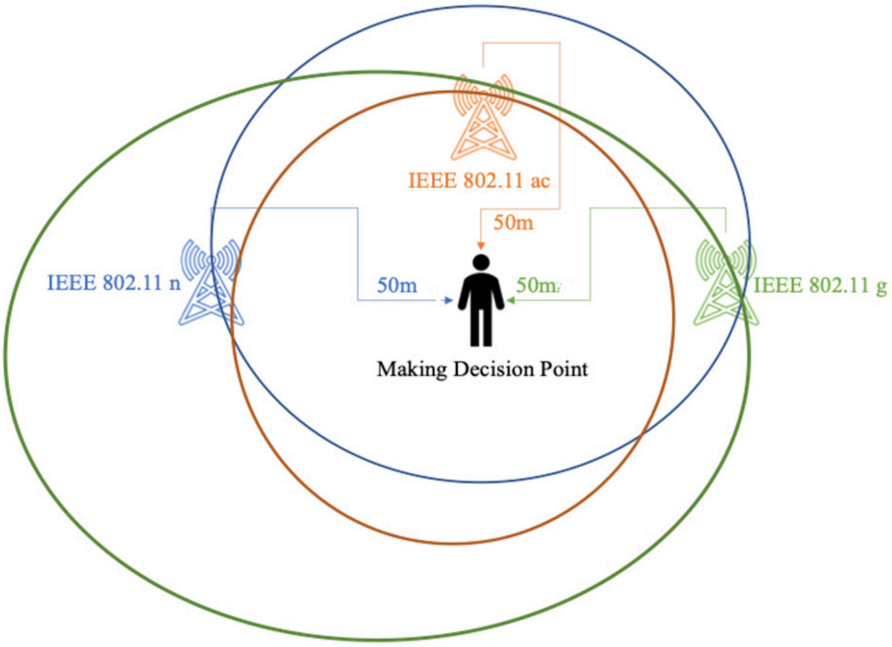

Fig. 2. Network topology simulation

The price per MB is equivalent to \$0.05, the length per packet is 1492, and the number of packets is 260 as noted by [37]. The values of a packet per size are equal to 1000 as noted in [35], and the distance is 50m. The relative significance of various attributes is examined in relation to the weights, through the use of a of pair-wise comparison based on the scale of relative importance (AHP method) as explained in Section 2.2. We selected four criteria with each having values out of 1. From Saaty scales for pair-wise comparison technique Table 1 in Section 2.2, we rank throughput as extremely important (0.4375), latency as very important (0.3125), the price per Mb as moderately important (0.1875), and BER as equally important (0.0625) for linear-TOPSIS simulation to be suitable for video streaming services. To determine the performance of the selection process, we utilized the following metrics throughput, latency, packet loss (BER) and price per Mb, to attain reliable results in Table 2.

4 The results and discussion

In the Linear-TOPSIS, Figure 3a illustrates that the algorithm picks the ideal candidate network based on the high throughput value and latency even with the high price of data rate flow as in Table 2. The method then selects a substitute most similar to the optimum solution. TOPSIS consideration of each attribute either takes a gradual increasing or decreasing network. The graph in Figure 3c illustrates the results of selection networks with exponential-TOPSIS algorithm, producing the same results when compared with the linear-TOPSIS. Figure 3b presents the results of three networks with logarithmic-TOPSIS algorithm. The change of weight resulted in negative values before normalizing. However, after normalizing, the algorithm picks the poorest network as the best candidate network. Thereby, we found that the linear and exponential TOPSIS algorithms have the same result and will constantly pick the ideal candidate network compared to logarithmic TOPSIS algorithm which instead, chooses the poorest network.

Table 2. The basic parameters for TOPSIS algorithm

Network Parameters	IEEE 802.11 g	IEEE 802.11 n	IEEE 802.11 ac
SNR	40	30	20
BW	20	40	80
Channel/modulation	256-QAM	64-QAM	16-QAM
Throughput (MB)	259	385	506
Latency (ms)	0.0747	0.0374	0.0188
Price per MB ($)	12.95	19.27	25.31
BER (10^{-3})	0.0015	0.0022	0.0006
Distance	50mm		
Price per Mb [$]	0.05$		
The number of packets	260		
Packet per size	1000		
Length of packet	1492		

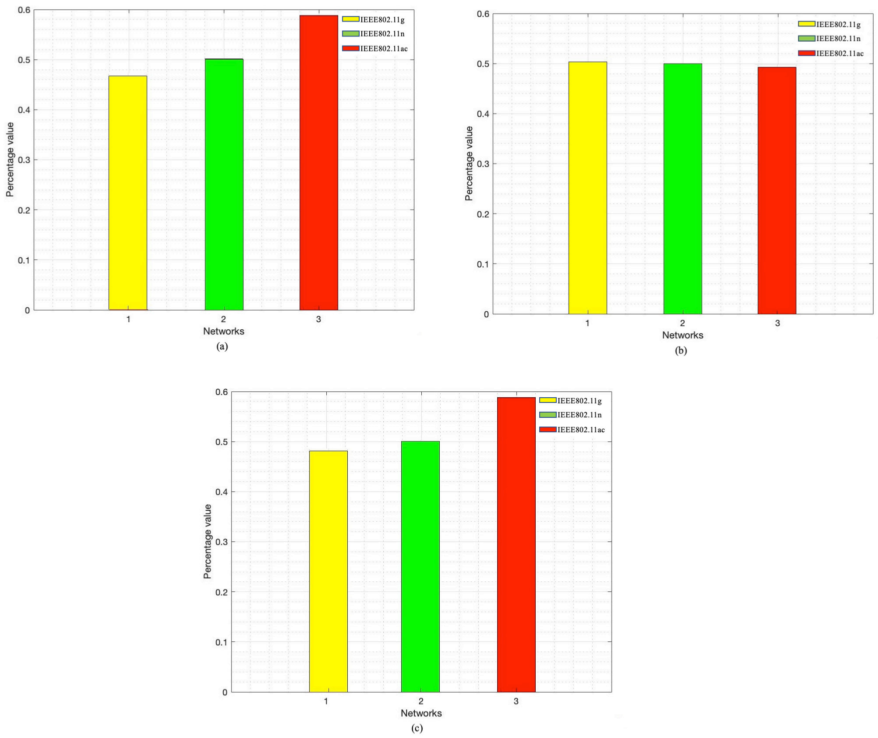

Fig. 3. The weightage versus network types for (a) linear-TOPSIS, (b) logarithmic-TOPSIS and (c) exponential-TOPSIS

5 Conclusions

In wireless networks, uninterrupted connection is a vital factor, with the need to prevent connection drop experienced by users in dynamic situations. This paper has focused on implementing the TOPSIS algorithm to select the best network to be used by a network client. The TOPSIS algorithm is implemented in the MATLAB environment and is examined under various parameter values. Different functions (logarithmic and exponential) affect the weights given for each attribute in the TOPSIS algorithm. The values of each weight are varied to show the effect of each function on the decision. We found out that the various functions have made other choices for each network under the same parameters. Besides, the simulation results showed that the use of functions affects the network selection predominantly. This effect demonstrated through the simulation of various weight parameters. Therefore, Linear-TOPSIS has given the best results, while logarithmic TOPSIS has produced the worst consequences. This research opens the doors widely to investigating modern intelligent algorithms like neural networks, fuzzy logic and other MCDM techniques like Gray Relational Analysis (GRE), Simple Adaptive Weighting (SAW) and Multiplicative Exponent Weighting (MEW)) to study the effects of these functions by using services such as video streaming, VoIP, data browsing in dynamic situations.

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