Evaluation MCDM Multi-disjoint Paths Selection Algorithms Using Fuzzy-Copeland Ranking Method

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Abstract**:** To increase the Internet's reliability and to have greater control over traffic transmission, reliable path selection is important and Multipath routing is promising technique that are used in the communication networks. Finding reliable end-end paths and backup can increase network performance. So, using proper decision metrics and algorithm should be used to paths and backup selection phase in these networks. For this goal, in this paper selecting a more reliable multi disjoint paths is addressed as a multi-criteria decision making (MCDM) problem and availability factor is defined and calculated based on network histories. For decision algorithm, a new fuzzy evaluation method is proposed to rank these multi disjoint paths selection algorithms and it is compared with bandwidth based, TOPSIS, FuzzyTOPSIS and AHP methods as candidate techniques to select more appropriate global disjoint paths in the IP/MPLS networks with packet loss, delay and availability parameters as decision making metrics. The proposed method combines fuzzy theory and Copeland method to evaluate the rank of each proposed method base on bandwidth, delay and new defined availability metric of selected end to end paths. Simulation results show that this method selects more reliable backup paths with better bandwidth in compared with others and can be used to path selection in IP/MPLS networks.

Keywords**:** Fuzzy-Copeland, Multi disjoint paths, Ranking method, AHP, TOPSIS**.**

1. Introduction

Using proper routing algorithms to find and select reliable paths and their backups for traffic transmission and failure resiliency purposes increase efficiency and fault tolerance in the networks. For this case, in the last few years, multi-path routing mechanisms have been proposed as a solution to the disconnectivity problem that appears by a link failure/withdrawal and redirect traffic from faulty paths to the alternate reliable paths [1-3]. Multipath routing are considered in the networking research community due to its advantages such as increased robustness, load balancing, reduced congestion Such as [4] that for video streaming transmission two link-disjoint paths are used for better throughput. It allows for load balancing and fast re-routing in order to improve the reliability and the efficiency of the network. Until now, different research studies are presented in this field and show the importance of failure recovery by using multipath routings.

In paper [5], packets distribution during multipath is introduced and implemented based on calculating round trip time(RTT) between source, intermediate nodes, and destination, bandwidth measurement, and overlap-aware degree to determine the most preferable routing path for network communication by using Ant Colony Optimization(ACO) but in this method, link/node failure is not considered for path selection and so end-to-end selected paths are not reliable during traffic transmission.

Another interesting research is suggested by Ishida and Yakoh [6] that an overlap aware path selection is implemented to enhance packet distribution. They defined the overlap degree as the shared links used in primary path and an alternative path. If an alternative path includes the same shared link used by primary path, the degree increases. It is due to avoid completely path failure when shared link becomes unavailable and traffic transmission is reliable. In fact, by avoiding overlap nodes in path selection phase, we can have disjoint path routing. In this paper normal path is better than alternative path. In [7] an approach for VPN (virtual private network) traffic engineering in Multiprotocol Label Switching networks using path protection for QoS and best effort traffic are presented. Path cycles are eliminated in their method to solve commonly link-based traffic engineering. Finding primary and backup paths is done by using a link-based approach based on off-line computation. It is shown that their algorithm in calculating link-disjoint and node-disjoint primary and backup paths for the QoS traffic is efficient in compared with similar cases.

In [8] failure- free LSPs is utilized to enhance the fault-tolerance and transmits the traffic of the failed LSP (the affected traffic) to destinations. Authors used IP tunneling technique and minimum cost metric to deter mine the amount of affected traffic to be transmitted by each failure-free LSP. Authors in [9] present an efficient algorithm that allows routers to enable more path diversity and a multipath routing scheme whose goal is to combine fast rerouting and load balancing loop-free routes. It is presented their algorithms has low overhead such as additional signaling messages and let nodes select distinct paths towards each destination to obtain good trade-off between path diversity and overhead.

In study [10], multiple paths are established from source node to destination node in order to improve transmission reliability and achieve load balancing. As study [11] described evaluation and analyze of the selection and scheduling of the impact factors of the nodes by the method of AHP, establishment of Evaluation System of Index System of ports and stations.

In some researches such as [12,13], bandwidth metric is used for routing selection. In these papers bandwidth constraint model is recommended to find proper paths. Many recovery mechanisms such as [14] just consider how to decrease packet losses via rerouting. They do not even take into account the traffic engineering or load balancing adjustment when a link or LSR is broken.

In study [15] Time Transitional AHP based on emergent policy in Cognitive Wireless Network is proposed. The proposal system is expected with cognitive wireless network consisted with multi wireless link and route, and the link and route selection is held by extensional AHP calculation with time transition. In [16] a multipath selection algorithm (MSA) is introduced for bandwidth based selection paths and traffic adjustment.

In this paper a multi disjoint path selection is considered as a multi-criteria decision making method and a new availability parameter are defined based on network history for decision metric for selecting reliable end-end paths. Our decision method is composed of Copeland ranking method and fuzzy theory to find most the reliable paths with greater bandwidth and lower delay. After that, our method is compared with other tree method AHP, TOPSIS and Fuzzy-TOPSIS for different scenarios and their performance are evaluated. The rest of this paper is organized as follows. Section 2 explains fuzzy theory and calculation of weight vector. In section 3 several multi disjoint paths selection algorithms based on MCDM problem and traffic distribution are introduced on these selected paths. In Section 4 Copeland ranking method is combined with fuzzy theory and the final evaluation list is made by considering wins-losses weights. Afterwards, section 5 discusses simulation results for the proposed multi disjoint paths methods. Finally in Section 6 some conclusions are made.

2. Fuzzy Theory and Calculating Weight Vector

The fuzzy set theory is introduced by Zadeh [17] and is employed for the uncertain data. Fuzzy goals and fuzzy constraints can be defined precisely as fuzzy sets in the space of alternatives. A fuzzy decision, then, may be viewed as an intersection of the given goals and constraints [18].

In fuzzy theory, there is a membership function in fuzzy set which represents the grade of each element. Membership degree for an element is defined by value between zero and one. Figure 1 indicates that triangular fuzzy number is defined as (l , m , u).

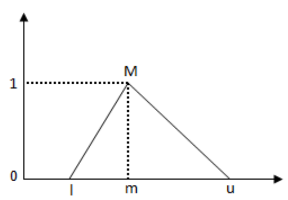

Figure 1. Triangular fuzzy number

Equations (1-4) define some operators which are used in fuzzy computation between two fuzzy number of M_i and M_j. In these equations l, m and u are elements of fuzzy numbers.

$$M_i = (l_i, m_i, u_i) \quad (1)$$

$$M_i^{-1} = \left(1/u_i, 1/m_i, 1/l_i\right) \quad (2)$$

$$M_i + M_j = (l_i + l_j, m_i + m_j, u_i + u_j) \quad (3)$$

$$M_i * M_j = (l_i * l_j, m_i * m_j, u_i * u_j) \quad (4)$$

In this paper, availability, bandwidth and delay are considered as three factors to find higher quality multi-disjoint paths in the network. So these suggested factors are compared by applying fuzzy scale. The fuzzy scale considering the relative importance to measure the relative weights is summarized in Table 1.

Table 1. Linguistic scales for importance

	Linguistic scales for importance	M	M^{-1}
1	Just equal	(1,1,1)	(1,1,1)
2	Equally Important	$(1/2, 1, 3/2)$	$(2/3, 1, 2)$
3	Weakly more Important	$(1, 3/2, 2)$	$(1/2, 2/3, 1)$
4	Strongly more Important	$(3/2, 2, 5/2)$	$(2/5, 1/2, 2/3)$
5	Very strongly More Important	$(2, 5/2, 5)$	$(1/3, 2/5, 1/2)$
6	Absolutely more important	$(5/2, 3, 7/2)$	$(2/7, 1/3, 2/5)$

For example in second line of table 1, the value of M is $(1/2, 1, 3/2)$ and by using equation (2) the value of M^{-1}= $(2/3, 1, 2)$. Following function explains how the value of this number can be computed. Based on equation (5) for each row of pairwise comparison matrix S_k is calculated as a new fuzzy number.

$$S_k = \sum_{j=1}^{n} M_{kj} * \left[\sum_{i=1}^{m}\sum_{j=1}^{n} M_{ij}\right]^{-1} \quad (5)$$

Comparing the degree of possibility between two triangular fuzzy numbers $S_i(l_i, m_i, u_i)$ and $S_j(l_j, m_j, u_j)$ is shown by $V(S_i \geq S_j)$. Equation (6) determines how the value of this comparison is obtained.

$$\begin{cases} V(S_i \geq S_j) = 1 & m_i \geq m_j \\ V(S_i \geq S_j) = \frac{(u_i - l_j)}{(u_i - l_j) + (m_j - m_i)} & \text{otherwise} \end{cases} \quad (6)$$

Using equation (7), the weight of each factor proposed in pairwise comparison matrix can be computed as follows.

$$W'(x_i) = Min\{V(S_i \geq S_j)\} \qquad k = 1,2,\ldots,m \qquad (7)$$

The normalized weight vector is calculated via equation (8) to convert fuzzy value W_i' to non fuzzy number W_i.

$$W_i = \frac{W_i'}{\sum W_i'} \qquad (8)$$

3. Introduction of Multi Disjoint Paths Selection Algorithms Based on MCDM Problem

3.1 MCDM Multi Disjoint Paths Selection Algorithms

3.1.1 AHP Based Multi Disjoint Paths Selection Algorithm

According to the class of network traffic, each link metric, namely, bandwidth, transmission delay and proposed availability can be used to select weight calculation. Therefore, each metric has a weight based on its importance in the decision maker. The decision maker employed is Analytical Hierarchy Process (AHP) that is a structured technique used to find the best solution based on the weight of metric according to their importance.

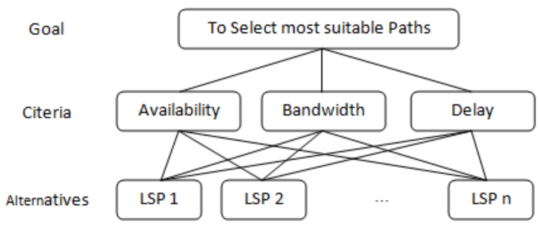

Figure 2. AHP method

Finding the best weight for each metric with AHP method will be done in the following steps. The first step is constructing evaluation matrix. This is a matrix which shows the weight of each metric in comparison with other metrics.

Table 2. AHP routing metric weights

	Availability	Bandwidth	Delay
Availability	1	m_1	m_2
Bandwidth	$1/m_1$	1	m_3
Delay	$1/m_2$	$1/m_3$	1

Where m_1, m_2, m_3 are the fuzzy scale considering the relative importance base on table 1.

Multiplying Matrix calculated by multiplying each row of the evaluation matrix and K^{th} root element of this matrix produces the K^{th} Root Matrix. By normalizing the AHP matrix, Eigenvector Matrix which shows the weights of factors can be obtained as Table 3.

Table 3. Normalized eigenvector matrix

	Multiplying	3^{th} Root	Eigenvector
Availability	$m_1 m_2$	$\sqrt[3]{m_1 m_2}$	$W_{availability}$
Bandwidth	m_3/m_1	$\sqrt[3]{m_3/m_1}$	$W_{bandwidth}$
Delay	$1/m_2 m_3$	$\sqrt[3]{1/m_2 m_3}$	W_{delay}
Sum			1

Having calculated the Eigenvector Matrix, one should now compute three other matrixes called E_a, E_b, E_d, which are considered as Availability Eigenvector Matrix, Bandwidth Eigenvector Matrix and Delay Eigenvector Matrix, respectively. Elements of these matrixes are:

$$a_{ij} = {}^{a_i}/_{a_j},\ b_{ij} = {}^{b_i}/_{b_j} \text{ and } d_{ij} = {}^{d_j}/_{d_i},$$

respectively. a_k, b_k and d_k denote availability, bandwidth and delay of link k, respectively. Finally AHP-Value of links in the network can be obtained as equation (9).

$$[\,c_1 \;\; \ldots \;\; c_k\,] = [\,E_a \;\; E_b \;\; E_d\,]_{k.3} \,.\, \text{Eigenvector Matrix} \qquad (9)$$

To study availability of a path, AHP-Values of links are used as members of that path. In this case, availability of a path is defined as the average availability of its links. Bandwidth of a path is extracted from minimum bandwidth of its links while delay of a path is the sum of delay calculated for links of a path. With this assumption, AHP-Value of links for a path can be calculated. Then, Evaluation Matrix will be constructed for paths using three Eigenvector Matrixes of E_a', E_b' and E_d'. After that AHP-Value for m paths of the network is obtained as equation (10).

$$[c_1' \;\; \ldots \;\; c_m'] = [E_a' \;\; E_b' \;\; E_d']_{m.3} \,.\, \text{Eigenvector Matrix} \qquad (10)$$

Then all disjoint paths are sorted by AHP-Value. The best paths are selected from top order of this list as the multi disjoint paths in AHP method.

3.1.2 TOPSIS Based Multi Disjoint Paths Selection Algorithm

TOPSIS method is based on the concept that the chosen alternative should have the shortest distance from the ideal solution and the farthest from the negative-ideal solution. Figure 3 depicts the concept of TOPSIS method.

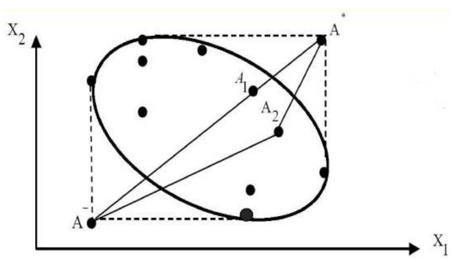

Figure 3. Finding solutions in TOPSIS method are based on distance

At first the un-normalized decision matrix is constructed as equation (11). In this matrix, x_{ij} describes the values of alternative A_i and factor F_j. In this paper all possible paths are considered as alternatives with availability, bandwidth and delay acting as the proposed factors.

$$D = \begin{matrix} \\ A_1 \\ A_2 \\ A_i \\ A_m \end{matrix} \begin{matrix} F_1 & F_2 & F_j & F_n \\ \end{matrix} \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (11)$$

Normalizing operation is done on elements of matrix D to compute normalized matrix R by using equation (12).

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} x_{ij}^2}} \quad (12)$$

After that the weighted normalized matrix should be calculated by multiplying normalized matrix R and vector W which is obtained from fuzzy method.

$$V = W \times R = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \cdots & w_j r_{1n} \\ w_1 r_{21} & w_2 r_{22} & \cdots & w_j r_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ w_1 r_{m1} & w_2 r_{m2} & \cdots & w_j r_{mn} \end{bmatrix} \quad (13)$$

Positive ideal solution (PIS) as the best solution and negative ideal solution (NIS) as the worse solution are described by equations (14) and (15).

$$V^* = \{v_1^*, \dots, v_n^*\} = \{(\max v_{ij} \mid j \in j), (\min v_{ij} \mid j \in j')\} \quad (14)$$

$$V^- = \{v_1^-, \dots, v_n^-\} = \{(\min v_{ij} \mid j \in j), (\max v_{ij} \mid j \in j')\} \quad (15)$$

Where, j represents the benefit factor and j' is the cost factor. Also V^* is the positive ideal solution and V^- is negative ideal solution. In this paper availability and bandwidth are benefit factors, whereas delay and packet loss are cost factors.
Distance between each element of matrix V and positive ideal solution can be computed by equation (16). S_{i^*} declares PIS distance.

$$S_{i^*} = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^*)^2} \quad i = 1,2,\dots,m \quad (16)$$

Equation (17) also shows the distance between v_{ij} and negative ideal solution (NIS). S_{i^-} declares NIS distance.

$$S_{i^-} = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^-)^2} \quad i = 1,2,\dots,m \quad (17)$$

Quality of the alternatives is assessed by distance of each alternative from the best as follows:

$$C_{i^*} = \frac{S_{i^-}}{S_{i^*} + S_{i^-}} \quad (18)$$

Finally, with respect to C_{i^*}, all alternatives can be ordered descending. In this way greater C_{i^*} means lower distance to the best solution while lower C_{i^*} declares great distance to the best solution. Having used this value for ordering all computed paths as the alternatives, leads to more proper paths at top order of this list.

3.1.3 FuzzyTOPSIS Based Multi Disjoint Paths Selection Algorithm

This method combines fuzzy theory and TOPSIS method to compute the weight of each factor for MCDM and solves problems in an uncertain condition effectively. In this method fuzzy MCDM (FMCDM) problems are expressed in positive triangular fuzzy numbers.

3.2 Traffic Distribution on Selected Paths

Traffic adjustment in the network is an important mechanism which can decrease packet loss and retransmission by load balancing in the network. In this paper, traffic management is done by defining weights and their assignment to each selected path. The weight of selected paths for load balancing and traffic adjustment is obtained from normalized weight W_k by equation (19).

$$W_k = \frac{P_k}{\sum_{i=1}^{n} P_i} \quad (19)$$
$$\text{s.t.} \sum_{i=1}^{n} W_i = 1$$

Where, W_k is the normalized weight of path k , P_k represents the weight of path k. In equation (19), P_k is calculated from equation (20).

$$P_k = \left(\left[\frac{AHP\_Cost(Path_k)}{\sum_{i=1}^{n} AHP\_Cost(Path_i)} \right] \right) \quad (20)$$

In equation (20) bandwidth and transmission delay of links specify the initialized value for AHP-Value of each link. Based on equation (19), the initialized traffic to each path can be defined with equation(21), where T_a is the allocated traffic to path k and T_g is the generated traffic in the source.

$$T_a\ (Path_k) = W_k\ T_g \quad (21)$$

Having allocated the initial traffic to the selected paths, these paths are monitored periodically. When the average difference between W_i and W_k becomes greater than a predefined threshold called dw_{th}, then path k will dynamically release part of its traffic called T_r (Eq. (22)).

$$T_r\ (Path_k) = \left(\frac{Avg(W_i) - W_k}{Avg(W_i)} \right) T_a\ (Path_k) \quad (22)$$

Where $Avg(W_i) = \frac{\sum_{i=1}^{n} W_i}{n}$ and $(Avg(W_i) - W_k) > dw_{th}$

This released traffic is divided into some other paths. For each $Path_j$ in the set of selected paths, if the difference between W_j and $Avg(W_i)$ is greater than zero, they can get part of $T_r\ (Path_k)$.

Paths with higher weight receive greater amount of the released traffic. Note that in the proposed algorithm, maximum bandwidth of a path should be considered before increasing the traffic called T_i which is obtained from equation (23). Paths with greater weight receive more amounts from the released traffic.

$$T_i\,(Path_j) = \left(\frac{w_j}{\sum_{i=1}^{n} w_i}\right) T_r\,(Path_k) \qquad (23)$$
$$(W_j \; - \; Avg(W_i\;)\;) > 0 \;\Rightarrow T_i\,(Path_j)$$

4. Copeland Ranking Method

Copeland is a method for ranking several alternatives according to the number of wins and losses for each determinative factor. The winner of an election is the candidate which is compared in turn with each of the other candidates and is preferred to the other candidates. All steps of Copeland ranking method are illustrated in Figure 4.

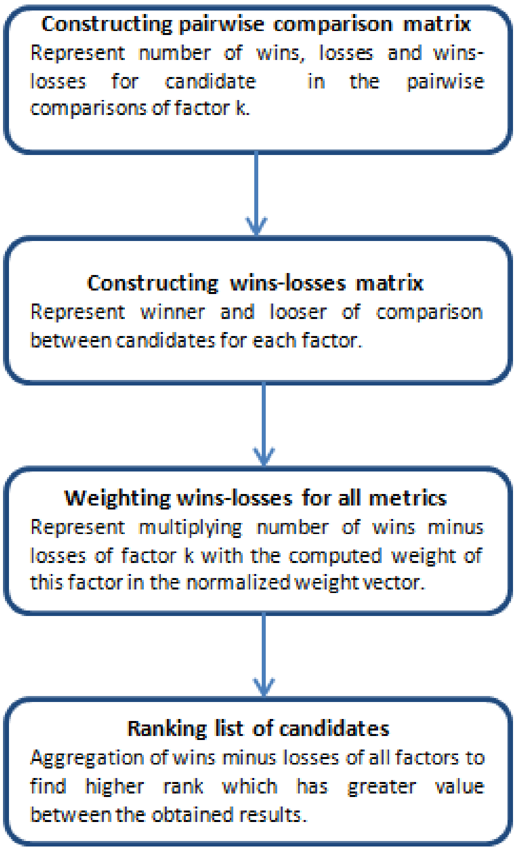

Figure 4. Steps of Copeland ranking method

First step in this method is constructing pairwise comparison matrix for the alternatives. Table 4 shows this matrix.

Table 4. Pairwise comparisons matrix

	A_1	A_2	...	A_j	...	A_n
A_1	-	$F_k(1,2)$	...	$F_k(1,j)$	...	$F_k(1,n)$
A_2		-	...	$F_k(2,j)$	...	$F_k(2,n)$
⋮			-	⋮	...	⋮
A_i				$F_k(i,j)$	...	$F_k(i,n)$
⋮					-	⋮
A_n						-

Each element $F_k(i,j)$ in Table 4 is comprised of two values. The first value is winner of the comparison between A_i and A_j for factor *K* while the second value is looser of them. Computation details are discussed below:

$$F_k(i,j) = \begin{cases} (A_i, A_j) & F_k(A_i) > F_k(A_j) \text{ and } i \neq j \\ (A_j, A_i) & F_k(A_i) < F_k(A_j) \text{ and } i \neq j \\ nothing & F_k(A_i) = F_k(A_j) \text{ or } i = j \end{cases} \qquad (24)$$

Considering the results of Table 5, the number of wins and losses can be calculated for each candidate. Table 5 has summarized these values.

Table 5. Wins-losses matrix

	WINS	LOSSES	WINS-LOSSES
A_1	$F_k^{w}(A_1)$	$F_k^{l}(A_1)$	$F_k^{w-l}(A_1)$
A_2	$F_k^{w}(A_2)$	$F_k^{l}(A_2)$	$F_k^{w-l}(A_2)$
⋮	⋮	⋮	⋮
A_i	$F_k^{w}(A_i)$	$F_k^{l}(A_i)$	$F_k^{w-l}(A_i)$
⋮	⋮	⋮	⋮
A_n	$F_k^{w}(A_n)$	$F_k^{l}(A_n)$	$F_k^{w-l}(A_n)$

Where,

$F_k^{w}(A_i)$: Number of wins for candidate A_i in the pairwise comparisons of factor *k*.

$F_k^{l}(A_i)$: Number of losses for candidate A_i in the pairwise comparisons of factor *k*.

$F_k^{w-l}(A_i)$: Number of wins minus losses for candidate A_i in the pairwise comparisons of factor *k*.

For each candidate, effective weight of the proposed factor is measured by multiplying number of wins minus losses of factor *k* with the computed weight of this factor in the normalized weight vector. This formula is shown in columns of Table 6 .

Table 6. Weighting wins-losses of each metric for candidate

	$w_{p_1} \times F_1^{w-l}(A_1)$	...	$w_{p_m} \times F_m^{w-l}(A_1)$
A_1	$w_{p_1} \times F_1^{w-l}(A_1)$	...	$w_{p_m} \times F_m^{w-l}(A_1)$
A_2	$w_{p_1} \times F_1^{w-l}(A_2)$	...	$w_{p_m} \times F_m^{w-l}(A_2)$
⋮	⋮	...	⋮
A_i	$w_{p_1} \times F_1^{w-l}(A_i)$	...	$w_{p_m} \times F_m^{w-l}(A_i)$
⋮	⋮	...	⋮
A_n	$w_{p_1} \times F_1^{w-l}(A_n)$	...	$w_{p_m} \times F_m^{w-l}(A_n)$

Final ranking list of the candidates can be calculated by aggregation of wins minus losses of all factors for each row in Table 7. In order to reach a fair condition, the better candidate with a greater value, get a higher rank between the obtained results. In Table 7 final ranking list for the proposed candidate is shown as r_k, where $1 \leq r_k \leq n$.

Table 7. Ranking list of candidates

	$\sum_{k=1}^{m} w_{p_k} \times F_k^{-1}(A_i)$	Rank
A_1	$\sum_{k=1}^{m} w_{p_k} \times F_k^{-1}(A_1)$	r_1
A_2	$\sum_{k=1}^{m} w_{p_k} \times F_k^{-1}(A_2)$	r_2
⋮	⋮	
A_i	$\sum_{k=1}^{m} w_{p_k} \times F_k^{-1}(A_i)$	r_i
⋮	⋮	
A_n	$\sum_{k=1}^{m} w_{p_k} \times F_k^{-1}(A_n)$	r_n

5. Simulation Results

In this paper the main goal is finding several multi-disjoint paths which have less packet loss, more reliability and finally less delay. So, the pairwise comparison matrix is constructed which is shown in Table 8.

Table 8. Pairwise comparison matrix for proposed metrics

	Availability	Delay	Packet Loss
Availability	(1,1,1)	$(2/3, 1, 2)$	$(1/2, 2/3, 1)$
Delay	$(1/2, 1, 3/2)$	(1,1,1)	$(1/2, 2/3, 1)$
Packet Loss	$(1, 3/2, 2)$	$(1, 3/2, 2)$	(1,1,1)

Base on the values of Table 8 and using Equations (1-8), the normalized weight vector is obtained as (0.61 , 0.15 , 0.24), which are respectively associated to packet loss, delay and availability metrics.

Figure 5 illustrates that the simulated network has 21 nodes with the parameters below: link delay is set 5 ms for all links; link bandwidth is set from 7 Mb to 20 Mb. Results of the simulation for this network are listed in Figs. 6–14.

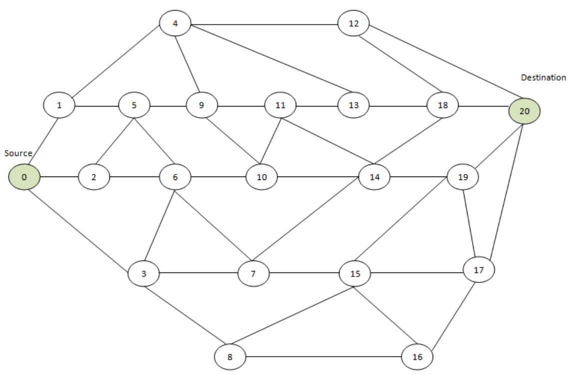

Figure 5. Proposed network with 21 nodes as a random topology

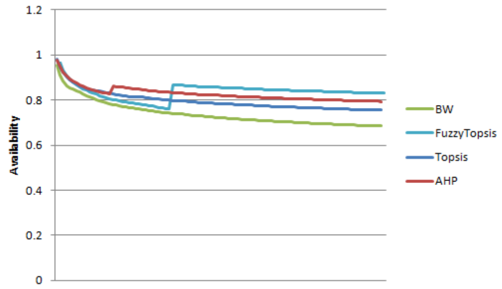

Figure 6. Comparison availability between four methods

Figures 7-10 illustrate the number of packet loss in a network comprised of 21 nodes for four proposed path selection methods. These figures show that by passing the time AHP and FuzzyTOPSIS method have less packet loss rather than two other methods.

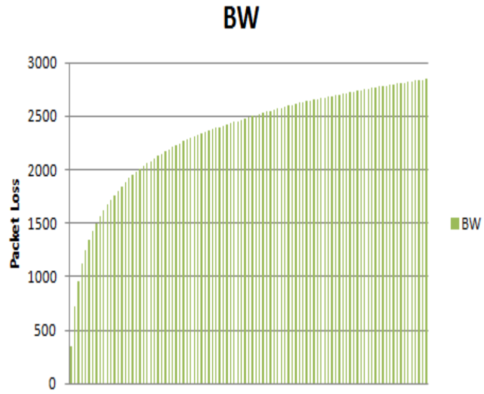

Figure 7. Packet loss in Bandwidth method

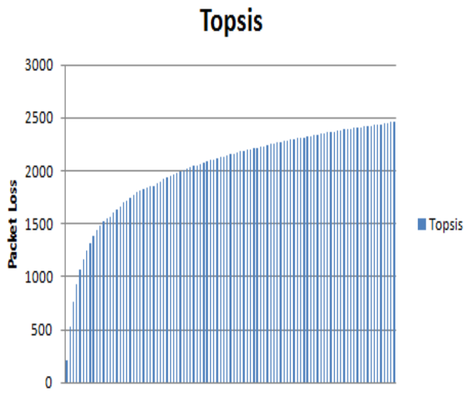

Figure 8. Packet loss in TOPSIS method

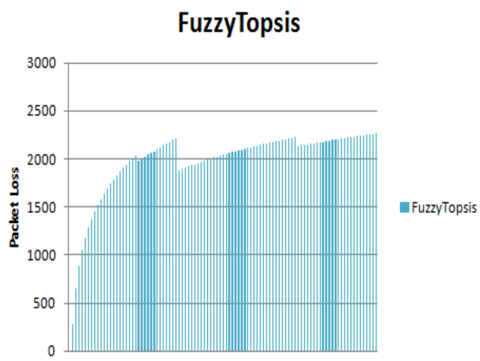

Figure 9. Packet loss in FuzzyTOPSIS method

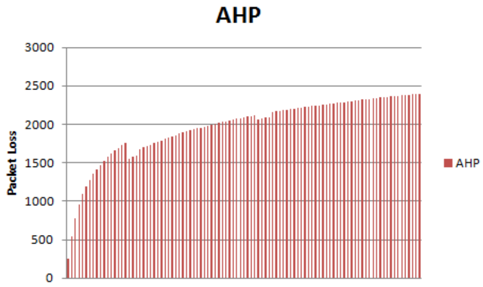

Figure 10. Packet loss in AHP method

Figures 11-13 show the average of packet loss, delay and availability as three discussed factors that are calculated totally for proposed methods. These figures show AHP method has best result in packet loss and delay. Also FuzzyTOPSIS method has the highest availability in four methods.

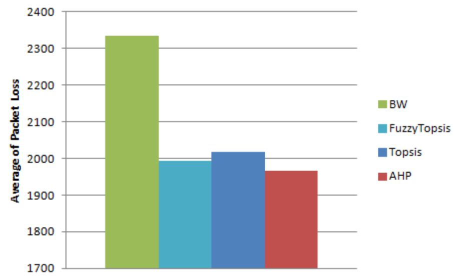

Figure 11. Comparison average of packet loss between four methods

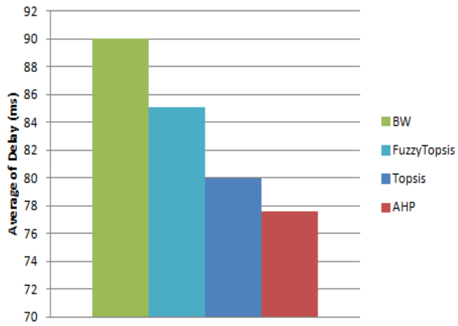

Figure 12. Comparison average of delay between four methods

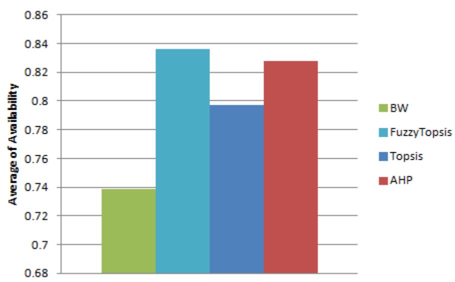

Figure 13. Comparison average of availability between four methods

Taking into account the obtained results, three pairwise comparison matrices are constructed by using equation (24). Tables 9-11 give these matrices. Each element in tables 9-11 is comprised of two values A_i and A_j. In (A_i,A_j), the first value is winner of the comparison between A_i and A_j for factor *K* while the second value is looser of them. Packet loss, delay and availability are three factors which are proposed in table 1, table2 and table 3 respectively. For example in table 9, cell(3,3) which declares comparison between FuzzyTOPSIS and AHP for packet loss factor is (A,F). This value represents AHP method is winner and FuzzyTOPSIS is looser because AHP method has lower packet loss than FuzzyTOPSIS method which is shown in figure 11.

Table 9. Packet loss pairwise comparisons matrix

	Bandwidth	TOPSIS	FuzzyTOPSIS	AHP
Bandwidth	-	(T,B)	(F,B)	(A,B)
TOPSIS	-	-	(F,T)	(A,T)
FuzzyTOPSIS	-	-	-	(A,F)
AHP	-	-	-	-

Considering figure 12 which shows the average of delay between four methods, cell(1,3) of table 10 with (A,B) value declares delay in AHP method is lower than Bandwidth method. In this cell AHP method is winner and Bandwidth method is looser.

Table 10. Delay pairwise comparisons matrix

	Bandwidth	TOPSIS	FuzzyTOPSIS	AHP
Bandwidth	-	(T,B)	(F,B)	(A,B)
TOPSIS	-	-	(T,F)	(A,T)
FuzzyTOPSIS	-	-	-	(A,F)
AHP	-	-	-	-

In table 11, comparison between four methods for availability factor is shown.

Table 11. Availability pairwise comparisons matrix

	Bandwidth	TOPSIS	FuzzyTOPSIS	AHP
Bandwidth	-	(T,B)	(F,B)	(A,B)
TOPSIS	-	-	(F,T)	(A,T)
FuzzyTOPSIS	-	-	-	(F,A)
AHP	-	-	-	-

In these matrices, *B* is the bandwidth method, *T* represents TOPSIS method, *F* indicates FuzzyTOPSIS method and *A* stands for AHP method. Afterwards, the number of wins and losses from the proposed candidates in the pairwise comparisons which is descript in table 5, are computed in tables 12-14 for each factor.

Table 12. Number of wins and losses for each candidate in the pairwise comparisons of packet loss

	WINS	LOSSES	WINS-LOSSES
Bandwidth	0	3	-3
TOPSIS	1	2	-1
FuzzyTOPSIS	2	1	1
AHP	3	0	3

The value of wins and losses in table 12 are calculated from number of winners and losers in table 9. In this table AHP method, FuzzyTOPSIS method, TOPSIS method and Bandwidth method has 3,2,1 and 0 wins respectively. Wins-losses column is computed from wins column minuses losses column.

Table 13. Number of wins and losses for each candidate in the pairwise comparisons of delay

	WINS	LOSSES	WINS-LOSSES
Bandwidth	0	3	-3
TOPSIS	2	1	1
FuzzyTOPSIS	1	2	-1
AHP	3	0	3

Table 14. Number of wins and losses for each candidate in the pairwise comparisons of availability

	WINS	LOSSES	WINS-LOSSES
Bandwidth	0	3	-3
TOPSIS	1	2	-1
FuzzyTOPSIS	3	0	3
AHP	2	1	1

Considering Table 8, (0.61 , 0.15 , 0.24) is taken as the normalized weight vector to compute weighting for wins-losses of three metrics in the four abovementioned methods. Table 15 illustrates the computation of results where $F_1^{w-1}(A_i)$ is the value of wins-loses of packet loss factor, $F_2^{w-1}(A_i)$ is the value of wins-loses of delay factor and $F_3^{w-1}(A_i)$ is the value of wins-loses of availability factor which are computed in table 12-14. In this table A_1, A_2, A_3 and A_4 are four proposed methods.

Table 15. Weighting wins-losses of three metrics for four proposed candidates

	$w_{p_1} \times F_1^{w-1}(A_i)$	$w_{p_2} \times F_2^{w-1}(A_i)$	$w_{p_3} \times F_3^{w-1}(A_i)$
Bandwidth	0.61×-3= -2.39	0.15×-3= -0.45	0.24×-3= -0.72
TOPSIS	0.61×-1= -0.61	0.15×1= 0.15	0.24×-1= -0.24
FuzzyTOPSIS	0.61×1= 0.61	0.15×-1= -0.15	0.24×3= 0.72
AHP	0.61×3= 2.39	0.15×3= 0.45	0.24×1= 0.24

Final results of computation which is shown in Table 16, ranks the developed methods. It is calculated by aggregation of wins minus losses of all factors for each row. For example AHP method has three weighting wins-losses values in table 15. By aggregating 2.39, 0.45 and 0.24 from table 15, ranking value of this method is achieved. So AHP method with the lowest average of delay and packet loss is placed at the top of ranking list. FuzzyTOPSIS, TOPSIS and Bandwidth methods are ranked in the next places, respectively.

Table 16. Ranking proposed methods

	$\sum_{k=1}^{m} w_{p_k} \times F_k^{w-1}(A_i)$	Rank
Bandwidth	(-2.39)+(-0.45)+(-0.72) = -3.56	4
TOPSIS	(-0.61)+(0.15)+(-0.24) = -0.7	3
FuzzyTOPSIS	(0.61)+(-0.15)+(0.72) = 1.18	2
AHP	(2.39)+(0.45)+(0.24) = 3.08	1

Finally the calculated rank value of four proposed methods are normalized and percentage of superiority between these methods is shown in figure 14.

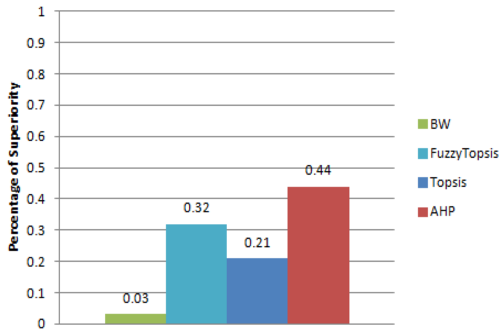

Figure 14. Percentage of superiority between four proposed methods

6. Conclusions

In this paper a multipath route selection algorithm is introduced based on combined fuzzy theory and Copeland algorithm. This method considers bandwidth, delay and a new availability parameter based on network history as decision metric for selecting reliable end-end paths. After that, our proposed algorithm is compared with other MCDM algorithms AHP, TOPSIS and Fuzzy-TOPSIS. . Simulation results show that this method selects more reliable backup paths with better bandwidth in compared with others and can be used to path selection in IP/MPLS networks.

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