Multi-criteria Handoff Decision making Algorithm for Seamless Mobility in Heterogenous Wireless Networks

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***Abstract* —Wireless networks have been through many transformations to provide Quality of Service (QoS) and seamless mobility. Handoff management plays a vital role in maintaining quality of service while roaming. The focus of the paper is to develop a handoff technique for optimized handoff decision making. Multi-Criteria Decision Making (MCDM) techniques are utilized for making decision where more than one contradicting parameter are involved. Fuzzy Analytic Hierarchy Process (FAHP) is used for weight calculation and Fuzzy Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) decides the rank of available networks. The proposed technique utilizes six network parameters i.e., received signal strength, bandwidth, signal to interference & noise ratio, delay, packet loss, and bit error rate for weights calculation under different traffic classes and three decision makers i.e., network, mobile node, and user preference for optimized handoff. The results show that the proposed technique effectively classify the best available network in terms of their rank and reduces the number of unnecessary handoffs.**

***Keywords*—Handoff, Handoff management, Parametric weights, Multi-Criteria Decision Making (MCDM), Fuzzy TOPSIS, FAHP**

I. Introduction

With the rapid growing era of digitization, industry is moving towards better accessibility and robustness. Fourth industrial revolution has totally changed the working of industries and has given a great boost to automation. Most of the work management tasks are conducted by mobile robots e.g., unmanned ground vehicles (UGVs). Mobile robots operate in wireless network of different Radio Access Technology (RAT). These radio access technologies provide the basic framework for communication. As more advancement has been made, the need of stable connection and best Quality of Service (QoS) is growing as well. This can be achieved by using different radio access technologies (RATs) i.e., WLAN, 3G, 4G etc. UGVs require network which can provide better quality of service and seamless mobility. In such a network, UGV move from one network to another. The task of switching from one RAT to another is overseen by mobility management feature.

A. Handoff

Handoff management is one of the main types of mobility management which deals with the connectivity of mobile node in a wireless network [1]. When a roaming mobile node leaps from one service area or base station (BS) to another, it is called handoff.

B. Handoff Process

The handoff process categorizes into three phases [2] which are as follows:

- Handoff Initiation Phase: Information is collected to identify whether handoff is required or not [3]. This information is usually in the form of data of different network parameters like signal strength, bandwidth, delay, signal to noise ratio etc.
- Handoff Decision Phase: Data acquired from initiation phase is processed under suitable criteria or decision-making algorithm which analyzes network parameters of every reachable access points.
- Handoff Execution Phase: Switch to a new network, based on decision taken in handoff decision phase.

Handoff decision phase decides when to make a handoff and which is the best network to connect. In a network with same type of radio access technology, mostly signal strength is utilized for decision making. In a network of different type of RATs, multiple network parameters are considered for decision making. The author of Ref. [4] showed that information related to network, mobile node, and user preference are utilized in a heterogenous network (different type of RATs). The information collected of each type is as follows:

- Network: Network Availability, Received Signal Strength (RSS), Signal to Noise ratio (SINR) etc.
- Mobile Node: Information related to battery status, speed, direction, working mode etc.
- User Preference: Information related to cost and required services.

Complex handoff decision algorithms are used for assessment and evaluating the parameters. Some of the

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techniques as handoff decision algorithm are fuzzy logic, artificial neural network, multi-criteria decision making (MCDM) etc.

Although many key contributions have been made to increase Quality of Service (QoS) and reduce number of unnecessary handoffs, novel articles are still acknowledged. Most of the past contributions mentioned in the literature review section uses only RSS value as a metric for performance evaluation of network while some use multiple network parameters for handoff decision making. It should be mentioned that using only one network parameter can initiate undesirable behavior e.g., ping pong effect under certain circumstances. Furthermore, some network parameters are more essential for seamless mobility than the other. Therefore, a weightage criterion is required for each traffic classes. This paper contributes are as follows:

- to enhance handoff decision making criteria by incorporating different traffic classes with set priority level.
- To develop a handoff algorithm involving six network parameters with different priority levels for each traffic classes.
- to improve handoff decision making by using Fuzzy based TOPSIS with multiple decision makers for handoff. Using multiple decision makers incorporates the involvement of network, user preference and mobile node in handoff decision making.
- To reduce the number of unnecessary handoffs by utilizing proposed handoff initiation criteria using closure coefficient value for best and current networks obtained from proposed technique.

This paper is divided into sections which are as follows: Section II discusses the application and limitation of different techniques used in the literature. Section III explains the working of proposed technique for handoff decision making. Results are discussed in Section IV and conclusion is provided in Section V.

II. Literature Review

In the past years many research and novel ideas related to mobility and handoff management in a homogenous, and heterogenous networks have been proposed. For a mobile node to have seamless connection and mobility, it is essential to select correct network parameters, assigning weights or priority based on their importance. It should incorporate different traffic classes like video, control, background etc. The following literature review covers different methods utilized for the selection of different parameters and handoff technique used.

Authors in [5] proposed a handoff decision algorithm based on neural networks. The decision is taken based on parameters like received signal strength, cost, and throughput (data rate). The results are compared with Simple Additive Weighting (SAW) based MCDM technique which shows that Artificial Intelligence (AI) based handoff decision algorithm limits handoff occurrence and delay, but it does not include any weighting criteria for parameters which make it less efficient for catering priority-based handoff decision making.

Weighted Rating of Multiple Attributes (WRMA) method [6] is proposed for weights calculation. For handover decision of network selection, Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) is used and results are compared with Analytic Hierarchal Process – SAW. Paper shows that TOPSIS is more precise and effective than other techniques. Five network parameters, which are delay, jitter, bandwidth, error, and cost, are selected for weights calculation using priority based WRMA technique but it only applies TOPSIS for just one traffic class instead of calculating combined weights for all traffic classes limiting the working to only one mode of class.

Authors in [7] proposed a fuzzy based handoff decision making algorithm which utilizes three fuzzy engines for quality, RSS, and decision parameter calculation. Results are compared with simple MCDM techniques like SAW and Analytical Hierarchal Process (AHP) which shows that proposed method is much simple and more efficient than others. But it does not include weightage calculation for network parameters and priority assessment of multiple traffic classes.

Handoff decision under heterogenous wireless network with Media Independent Handover FUNCTION (MIHF) in [8] network simulator 2 (NS-2) was proposed, using velocity of mobile node and coverage area of access points as network parameter. The research showed that using velocity and coverage area as network parameter reduces the unnecessary handoffs and eventually enhancing QoS. Due to no weight assignment of network parameters and priority assessment of traffic classes, technique will show decrease in QoS when used for priority-based handoff decision making.

Authors in [9] proposed Modified Optimization (M-OPTG) based vertical handoff (VHO) or horizontal handoff (HHO) algorithm using RSS, load balancing, battery life and velocity as network parameters. The load balancing, handoff occurrence, and call dropping analysis are done using Network Simulator 2 (NS-2). Results showed that M-OPTG improves QoS, battery life and reduces call dropping occurrence. The technique give priority to RSS of WLAN over cellular networks while ignore other network parameters like delay, bandwidth, signal to noise ratio etc. Due to its focus on RSS, technique is only limited to application which require high RSS value.

A Software Defined Network (SDN) based [10] approach combined with fuzzy logic utilized for handoff management under multiple network parameters i.e., current RSS, forecasting RSS and available bandwidth is adopted for calculating performance value for each network by fuzzy logic for the selection of optimal network. Using two layered setup improves the QoS of handoff process and reduces unnecessary load on the network but it uses three network parameters and increasing the number of parameters will exponentially increase the number of fuzzy rule sets to define.

The authors of [11] proposed a fuzzy based handoff initiation criteria based on different network parameters and user preference. The threshold value for the handoff initiation is calculated using network-controlled strategy. The technique reduces the unnecessary handoff and cater different traffic classes. Provided the solution for ping-pong problem (continuous handoff) but does not elaborate the handoff decision making criteria.

The authors of research in [12] proposed adaptive modular fuzzy based handoff decision system (AMHDS) design II for network selection in handoff decision making. Result shows that AMHDS design II significantly improves efficiency of simple AMHDS and reduces the number of fuzzy rule set required. It works on multiple modules based fuzzy engines linked together to give a handoff decision output. The limitation of this technique is that, firstly its inability to tackle mobility management and secondly number of rule set requires increase exponentially with the increase of network parameters.

Authors in [13] proposed fuzzy based handoff decision method using gray method for prediction. It predicts the RSS value to set the required threshold. Results shows that it reduces number of unnecessary handoffs and provide QoS when compared with single factor vertical handoff algorithm. Since it only utilizes RSS for handoff decision making, it can only be used for application where RSS value is of high importance and cannot be used for handoff decision making for multiple traffic classes.

Using multi-layered network-controlled handoff algorithm in [14] for handoff execution in Long-Term Evolution (LTE) network reduces the inter-packet time compared to traditional technique. Utilizing RSS as network parameter for handoff can initiate ping pong effect which can be catered by increasing the number of network parameters, assigning priority weights.

Grouped handoff management scheme proposed in [15] utilizes mobile relay node to act as a collective representative of multiple mobile nodes or users. In doing so, it reduces the number of handoffs and service drops in the network. The handoff process is further improved to decrease the service drop rate. Handoff algorithm proposed in [16] improved the overall QoS for seamless connectivity in LTE-A networks using femtocells. Number of handoffs were reduced, and ratio of femtocells (targeted) were improved. Further improvements can be made in reducing the number of handoffs and power cost by setting power levels of each node in multilayers cells and tuning the position of each access point.

Authors in [17] provided an extensive review on handoff management from Long-Term Evolution (LTE) to 5G New Radio (NR). Many advantages and disadvantages of algorithms and methods for efficient handoffs are discussed. Key challenges faced and main issue for efficient handoff in LTE to NR are discussed.

The authors of [18] proposed Chi-Square distance-based handoff decision algorithm for network selection. It incorporates weights calculation of each parameter under different traffic classes by subjective and objective weight calculation method. Chi-square distance is difference of most ideal values of each parameter to actual value. Results shows that chi-square method not only select best available network but also tackle problem of trapping in local maxima. However, it deals each traffic class separately and cannot find one best available network for all traffic classes.

Handoff management in paper [19] was done by acquiring data of each neighbor access point and forming a neighbor table. Mobile host assess the neighbor table for re-association with new access point. The algorithm is simple and effective in reducing handoff delay time and does not require computation. However, incorporation of different traffic class and network parameters were not considered. Mobile host connect to the new access point if it is available irrespective of the best available network.

Using 5g technology for LTE and mm wave communication [20] with q-learning based algorithm for handoff initiation with two network parameters i.e., speed and RSS. Fuzzy convolutional neural network (CNN) based handoff algorithm with five network parameters for handoff decision making reduces the number of unnecessary handoffs and selects the best network based on 32 fuzzy set rules. Quick convolution reduces the CNN processing time and jelly fish algorithm is adopted for selecting possible routes and transfer of information.

Utilizing moving average slope of RSS as network parameter [21] to reduce the number of handoffs and cater ping pong effect to improve QoS of handoff process. Slope of network parameter is used as handoff initiation criteria and RSS value is used as network ranking parameter i.e., high RSS value more favorable network. Selection is done based on highest RSS value. Using multiple parameters with priority weights could further improve the handoff decision algorithm for handoff management in heterogenous wireless networks.

Authors in [22] proposed fuzzy logic-based handoff initiation and for network selection collective data-rates of individual application or traffic classes are used. The paper uses If-Then rule for making handoff initiation decision using bandwidth, velocity, and network load as network parameters. But the technique gets complicated as more network parameters are added and due to no weight assigned to network parameter efficient handoff decision will be compromised.

The authors of [23] proposed improved MCDM based weight assessment and decision making. Entropy weighting method and multi-objective optimization based on ratio analysis (E-MOORA) is adopted for weight calculation and handoff decision making. The technique efficiently makes handoff decision and reduces handoff failures. Results are compared with grey rational analysis-based handover (GRA_HO) method and shows considerable improvements.

Above discussion shows that there are numerous methods and techniques that optimize system based on one parameter. There are some techniques which uses multiple network parameters but either not utilize weights calculation for each parameter or do not include optimization based on traffic classes. Defining traffic classes, selecting network parameter, and weights calculation are important steps in handoff decision making. Without any of them, accuracy of handoff decision would be affected. The proposed method solves this problem by using a handoff decision algorithm that includes prioritization of multiple traffic classes, proper weights assessment for network parameters using FAHP, and optimize handoff decision making using Fuzzy TOPSIS.

III. Proposed Methodology

Proposed method for handoff management in heterogenous network involves identification of traffic classes, selection of network parameters, assigning priority to parameters for each class, weights calculation and network selection. From different MCDM techniques, Fuzzy AHP is chosen for weight calculation and Fuzzy TOPSIS is adopted for handoff decision making. The overall working of handoff management is divided into the following phases:

C. Selection of Network Parameters and Traffic Classes

Selection of network parameters and traffic classes are important steps since they are the deciding factors in handoff decision making. In proposed technique, three traffic classes are used i.e., Control, Video, and Background. Table II in [24] shows network parameters and their ranks for network, mobile and user preference. Parameters with high ranks are chosen for handoff management which are as follows:

- Received Signal Strength Indicator (RSSI)
- Bandwidth (BW)
- Signal to Interference & Noise Ratio (SINR)
- Delay
- Packet Loss (PL)
- Bit Error Rate (BER)

TABLE I. PRIORITY CRITERIA OF NETWORK PARAMETER FOR EACH TRAFFIC CLASS

Traffic Class	Network Parameter					
	RSSI	BW	SINR	Delay	PL	BER
Control	1	6	5	4	3	2
Video	5	1	6	2	4	3
Background	1	2	3	4	5	6

TABLE II. RELATIVE IMPORTANCE CRITERIA

Importance Level	Importance Value	Fuzzy Value
Equal	1	(1,1,1)
Moderate	3	(2,3,4)
Strong	5	(4,5,6)
Very Strong	7	(6,7,8)
Extreme	9	(9,9,9)
Intermediate Values	2,4,6,8	(1,2,3), (3,4,5), (5,6,7), (7,8,9)
Value for inverse comparison	1/3, 1/5, 1/7. 1/9	

Each network parameter could have different priority level in different traffic classes like in video class, bandwidth and delay are more important than RSSI while in control class, RSSI is more important. Table I shows the priority criteria of network parameters for each traffic class. Before entering phase-II, pair-wise comparison matrix for each traffic class is calculated. To generate pair-wise comparison matrix for a specific traffic class, each parameter is compared to other network parameters and its relative importance value is decided based on priority criteria shown in Table I and using relative importance value in Table II.

D. Parametric Weights Calculation

Weights of each traffic class are calculated from Fuzzy Analytical Hierarchy Process (FAHP) using Geometric Mean. Steps involve in the process are as follows:

Fuzzification: Each entity in pair-wise comparison matrix is fuzzified using Table II. The fuzzy value for inverse comparison is obtained by taking inverse of their respective fuzzy reciprocal using Eq. (1).

$$(\alpha,\beta,\gamma)^{-1} = (1/\gamma\ , 1/\beta\ , 1/\alpha) \quad (1)$$

Fuzzy Geometric Mean: Fuzzy geometric mean (FGM) of each row is calculated using Eq. (2).

$$FGM = \sqrt[n]{\prod r_i} \quad (2)$$

where n is the number of columns in the pair-wise comparison matrix and r_i represents fuzzy value in nth column of respective row.

Fuzzy Weights Calculation: For calculating fuzzy weights, inverse of summation of fuzzy geometric mean (ISFM) is determined. The product of FGM of a network parameter with ISFM gives its respective fuzzy weight (FW) as in

$$FW = FM_i \times (FM_1 + FM_2 + FM_3 + \ldots + FM_n)^{-1} \quad (3)$$

where i = 1, 2, 3…, n and n represent number of parameters. Inverse of the fuzzy number is calculated using Eq. (1).

E. Handoff Decision Making

In this phase, three Decision Matrices (DM) are obtained from three decision makers i.e., network, mobile node, and user. The decision matrix is the assessment of available networks under chosen network parameters. The following Tables III−V provide the decision matrix used for making handoff decision making using Fuzzy TOPSIS.

TABLE III. DECISION MATRIX FOR NETWORK

Network	Network Parameter					
	RSSI	BW	SINR	Delay	PL	BER
Network 1	3	5	3	4	4	3
Network 2	4	5	4	3	4	4
Network 3	5	3	5	2	5	4
Network 4	2	3	2	1	2	1

TABLE IV. DECISION MATRIX FOR USER PREFERENCE

Network	Network Parameter					
	RSSI	BW	SINR	Delay	PL	BER
Network 1	4	5	5	4	5	4
Network 2	4	4	5	3	4	3
Network 3	5	3	3	1	3	3
Network 4	2	3	3	1	3	2

TABLE V. DECISION MATRIX FOR MOBILE NODE

Network	Network Parameter					
	RSSI	BW	SINR	Delay	PL	BER
Network 1	3	4	4	4	4	4
Network 2	4	3	3	3	3	3
Network 3	4	3	2	2	1	2
Network 4	1	2	1	1	1	1

The three decision matrices are fuzzified and combined to create a fuzzy combined decision matrix (FCDM). The fuzzy weights calculated for each traffic class are combined to create combined fuzzy weights (CFW). The conditions to calculate FCDM and CFW is shown below:

$$X_{ij} = (\alpha_{ij} , \beta_{ij} , \gamma_{ij}) \tag{4}$$

$$\alpha_{ij} = \min (a^{k}_{ij}) \tag{5}$$

$$\beta_{ij} = (\Sigma^{k} b^{k}_{ij})/k \tag{6}$$

$$\gamma_{ij} = \max (c^{k}_{ij}) \tag{7}$$

where Xij represents the combined fuzzy value and k is the number of fuzzy values to combine. CFW and FCDM obtained are then used in Fuzzy TOPSIS for decision making. Steps involve in Fuzzy TOPSIS are as follows:

Normalized Fuzzy Combined Decision Matrix (NFCDM): FCDM is normalized based on beneficial and non-beneficial parameters using Eq. (8, 9).

For beneficial parameters:

$$NFCDM_{ij} = FCDM_{ij} / c^{*}_{j} \tag{8}$$

For non-beneficial parameters:

$$NFCDM_{ij} = a^{*}_{j} \times (FCDM_{ij})^{-1} \tag{9}$$

where c*j = max(ckij), a*j = min(akij)

Fuzzy Weighted Combined Decision Matrix (FWCDM): NFCDM is of the order (n × m) and CFW calculated is of the order (m × 1), where n is the number of available networks and m is the number of network parameters. Each column of NFCDM is multiplied with CFW for determining fuzzy weighted combined decision matrix (FWCDM) using Eq. (10).

$$FWCDM_{ij} = NFCDM \times CFW, \text{ where } j=1,2, \ldots,m \tag{10}$$

FPIS and FNIS: The next step is to calculate positive ideal solution and negative ideal solution. It is done by using the best possible values of for positive ideal solution and worst possible values for negative ideal solution. These values are taken from FWCDM. In FWCDM, each fuzzy number has three values. For beneficial parameter, fuzzy number with maximum value in third column is taken. If more than one fuzzy number has the same maximum third value, then second column values are compared and then first column values. For non-beneficial parameter, fuzzy number with minimum value in first column is taken. If more than one fuzzy number has the same minimum first value, then second column values are compared and then third column values. The process is used for every network parameter in FWCDM to create fuzzy positive ideal solution (FPIS) matrix and fuzzy negative ideal solution (FNIS) matrix for each network parameter.

$$FPIS_i = \max (FWCDM_{j3}) \tag{11}$$

$$FNIS_j = \min (FWCDM_{j3}) \tag{12}$$

Distance Calculation: The distance of each entity in FWCDM from FPIS and FNIS is calculated using Eq. (13) where (a1, b1, c1) are from FWCDM and (a2, b2, c2) are from FPIS or FNIS. This creates two matrices of same order as FWCDM i.e., one for distance from positive ideal solution (Dp) and other for distance from negative ideal solution (Dn).

$$d_{ij} = \sqrt{} ((a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2) /3 \tag{13}$$

To calculate total positive (Ds) and negative (Dq) distances of each available network, all the entities in each row of Dp and Dn are added using Eq. (14) where j is the number of network parameters.

$$D_{s \text{ or } q} = \Sigma^{j} D_{(p \text{ or } n)\, j} \tag{14}$$

Closure Coefficient: Network ranking is decided by the closure coefficient (CC) of each network. Network with high closure coefficient is ranked higher than the other. Its value is calculated using Eq. (15).

$$CC_i = D_{q,i} / (D_{q,i} + D_{s,i}) \tag{15}$$

where i is the number of available networks.

F. Handoff Initiation Criteria

Handoff is initiated when the difference between the current value of CC and highest available value of CC is greater than a set value i.e., threshold. Using the handoff initiation criteria in Fig. 1, will reduce number of unnecessary handoffs and cater the ping pong effect. Fig. 2 shows the overall working flow chart of network selection process.

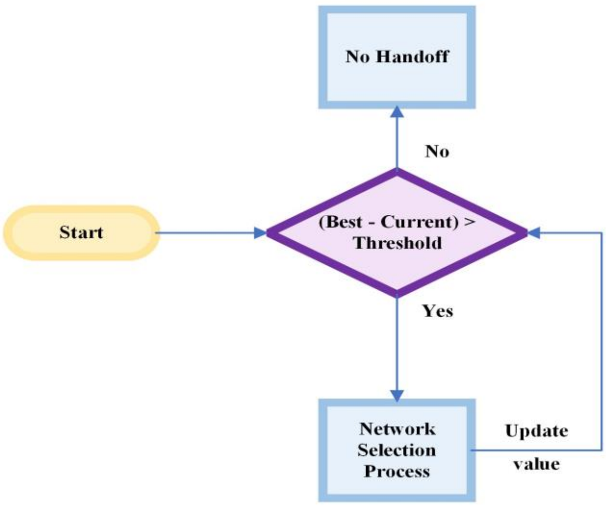

Figure 1. Flowchart of handoff initiation process.

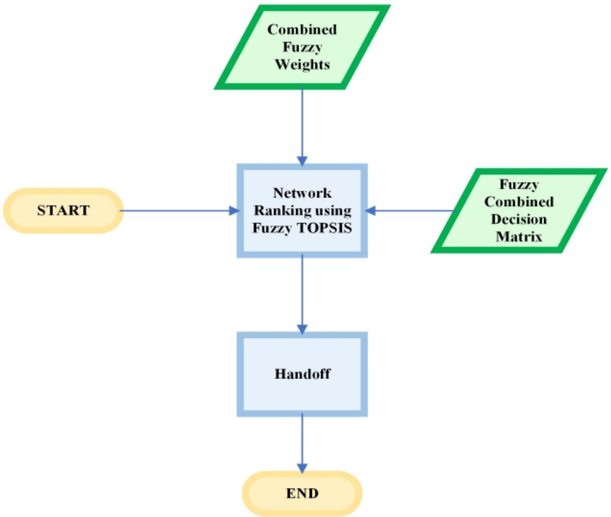

Figure 2. Flowchart of network selection process.

IV. Result and Discussion

This section discuses two aspects i.e., weights of network parameter and network ranking. Parametric weights are obtained using FAHP and for network ranking Fuzzy TOPSIS is used.

The de-fuzzified weights of each network parameter for different traffic classes are given in Table VI. Centre of Area (CoA) is used as the de-fuzzification method for fuzzy weights of FAHP. The graphical representation of FW is shown in Fig. 3.

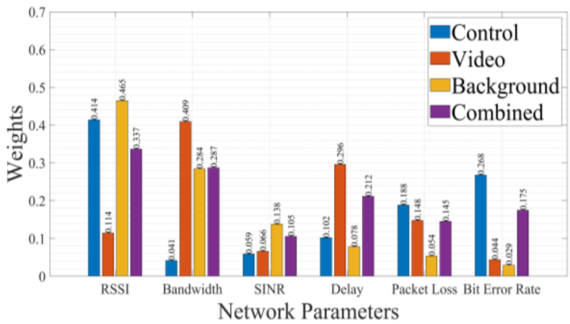

Figure 3. Fuzzy weights of network parameters for different traffic classes.

TABLE VI. FAHP Weights under Different Traffic Classes

Parameters	Traffic Classes			
	Control	Video	Background	Combined
RSSI	0.4141	0.1143	0.4649	0.3365
Bandwidth	0.0415	0.4095	0.2844	0.2873
SINR	0.0590	0.0661	0.1378	0.1054
Delay	0.1019	0.2960	0.0781	0.2116
Packet Loss	0.1883	0.1475	0.0536	0.1451
Bit Rate Error	0.2680	0.0438	0.0293	0.1748

For control class, RSSI is more important than bandwidth while in video class, bandwidth is given more weightage than RSSI, which is in accordance with the priority criteria in Table I. The network ranking and value of closure coefficient obtained from fuzzy and non-fuzzy TOPSIS are given in Table VII which shows that network three has highest CC value and has Rank 1.

TABLE VII. Network Ranking and Closure Coefficient using TOPSIS and Fuzzy TOPSIS

Available Network	Closure Coefficient		Rank	
	F-TOPSIS	TOPSIS	F-TOPSIS	TOPSIS
Network 1	0.3560	0.4688	4	3
Network 2	0.4258	0.5819	3	2
Network 3	0.7996	0.6589	1	1
Network 4	0.5996	0.4119	2	4

The graphical representation is shown in Fig. 4, which provides more detailed comparison of network ranking. Fig. 3 shows that RSSI and bandwidth have the highest combined weights so handoff decision depends heavily on the value of these parameters. Delay and Bit error rate has moderate values but higher than Packet loss and SINR, so their values have higher impact on handoff decision than SINR. The Network 3 has higher values of RSSI, bandwidth, and lower value of delay than other networks.

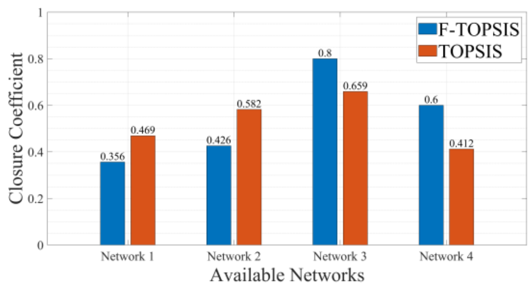

Figure 4. Comparison of closure coefficient of available networks.

So, it has high CC value and rank which makes it best available network. Results are compared with TOPSIS using same weights and decision matrices. The comparison of results verifies the ranking of F-TOPSIS. The reason of ambiguity in the rank of Network 4 is both techniques have different criteria for the combination of decision matrices. Instead of averaging, fuzzy TOPSIS uses a specific criterion to merge decision matrices using Eqs. (4–7).

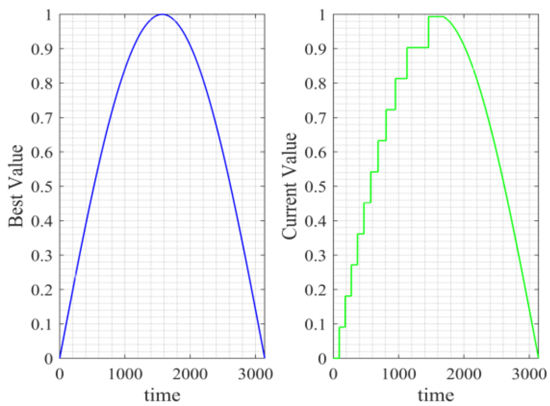

Figure 5. Graphical representation of varying best and current CC values for threshold value of 0.09.

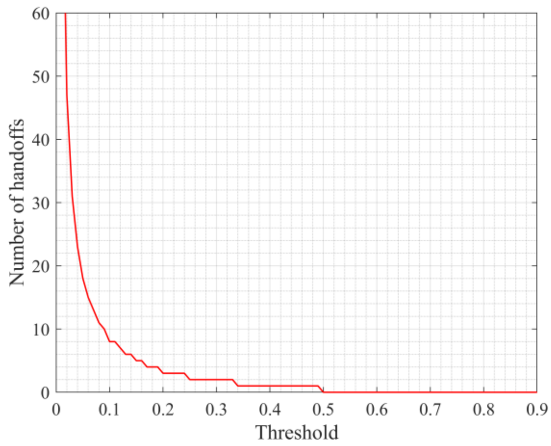

Figure 6. Number of handoffs over different threshold values.

The handoff initiation criteria proposed reduces the number of handoffs (NoHs) by using suitable threshold. Number of handoffs for a threshold are calculated by using sinusoidal curve as varying best CC value as shown in Fig. 5 (a). Handoff is initiated whenever difference between best and current CC value is greater than set threshold, represented as steps in Fig. 5 (b) for threshold value of 0.09. The experiment is repeated for multiple threshold values. Graphical representation of number of handoffs for multiple threshold values are shown in Fig. 6.

V. Conclusion

The paper proposes Fuzzy based MCDM techniques for calculating priority weights of selected network attributes and rank of available networks. Parametric weights are calculated using FAHP for each traffic class separately and then combined in handoff decision making process by Fuzzy TOPSIS, which uses decision matrices to rank available networks. The fuzzy based approach is used to effectively manage the values of network parameters for better handoff decision making. The incorporation of parametric weights under different traffic classes optimizes the overall QoS of handoff management and reduces the number of unnecessary handoffs.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Muhammad Wajid Khan: Research, conceptualization and write up. Umar S. Khan: Writing and supervision. Muhammad Mubasher Saleem: Proof reading and simulation. Nasir Rashid: Results validation.

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References

[1] J. Xie and S. Mohanty, “Mobility management in wireless systems,” *Telecommunication Systems and Technologies*, vol. 2, no. 5, p. 162, 2009.

[2] A. Kammoun and N. Tabbane, “Fuzzy utility decisional vertical handover algorithm for enhancing network performances,” in *Proc. International Conference on Multimedia Computing and Systems - Proceedings*, Apr. 2017, pp. 337–343, doi: 10.1109/ICMCS.2016.7905604

[3] M. Kassar, B. Kervella, and G. Pujolle, “An overview of vertical handover decision strategies in heterogeneous wireless networks,” *Computer Communications*, vol. 31, no. 10. pp. 2607–2620, Jun. 25, 2008, doi: 10.1016/j.comcom.2008.01.044

[4] J. Márquez-Barja, C. T. Calafate, J. C. Cano, and P. Manzoni, “An overview of vertical handover techniques: Algorithms, protocols and tools,” *Computer Communications*, vol. 34, no. 8. Elsevier B.V., pp. 985–997, Jun. 01, 2011, doi: 10.1016/j.comcom.2010.11.010

[5] A. Çalhan and C. Çeken, “Artificial neural network based vertical handoff algorithm for reducing handoff latency,” *Wireless Personal Communications*, vol. 71, no. 4, pp. 2399–2415, Aug. 2013, doi: 10.1007/s11277-012-0944-4.

[6] S. J. Yang and W. C. Tseng, “Design novel weighted rating of multiple attributes scheme to enhance handoff efficiency in heterogeneous wireless networks,” *Computer Communications*, vol. 36, no. 14, pp. 1498–1514, Aug. 2013, doi: 10.1016/j.comcom.2013.06.005

[7] P. Tillapart, T. Thumthawatworn, P. Viriyaphol, and P. Santiprabhob, “Intelligent handover decision based on fuzzy logic for heterogeneous wireless networks,” in *Proc. 12th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON)*, 2015, pp. 1-6, doi: 10.1109/ECTICon.2015.7207076

[8] A. Jain and S. Tokekar, “Application based vertical handoff decision in heterogeneous network,” in *Procedia Computer Science*, 2015, vol. 57, pp. 782–788. doi: 10.1016/j.procs.2015.07.475.

[9] T. Velmurugan, S. Khara, and B. Basavaraj, “Modified handoff algorithm for providing optimization in heterogeneous wireless networks,” *Evolving Systems*, vol. 6, no. 3, pp. 199–208, Sep. 2015, doi: 10.1007/s12530-015-9135-3

[10] M. Sun and H. Qian, “Handover management scheme in SDN-based wireless LAN,” *Journal of Communications*, vol. 11, no. 3, pp. 282–289, Mar. 2016, doi: 10.12720/jcm.11.3.282-289.

[11] P. Dhand and S. Mittal, “Smart handoff framework for next generation heterogeneous networks in smart cities,” in *Proc. ACM International Conference Proceeding Series*, August 2016, doi: 10.1145/2979779.2979854

[12] T. Thumthawatworn, P. Tillapart, and P. Santiprabhob, “Adaptive multi-fuzzy engines for handover decision in heterogeneous wireless networks,” *Wireless Personal Communications*, vol. 93, no. 4, pp. 1005–1026, Apr. 2017, doi: 10.1007/s11277-017-3963-3

[13] L. Zhang, L. Ge, X. Su, and J. Zeng, “Fuzzy logic based vertical handover algorithm for trunking system,” in *Proc. 26th Wireless and Optical Communication Conference (WOCC)*, 2017, pp. 1-5, doi: 10.1109/WOCC.2017.7928995

[14] P. Singkaew, A. Jansang, and A. Phonphoem, “Handover algorithm between femtocells in Long Term Evolution (LTE) network,” *Journal of Communications*, vol. 13, no. 4, pp. 187–192, Apr. 2018, doi: 10.12720/jcm.13.4.187-192

[15] O. O. Omitola and V. V. M. Srivastava, “Group handover strategy for mobile relays in LTE-A networks,” *Journal of Communications*, vol. 13, no. 9, pp. 505–511, Sep. 2018, doi: 10.12720/jcm.13.9.505-511.

[16] O. O. Omitola and V. M. Srivastava, “An improved handover algorithm for lte-a femtocell network,” *Journal of Communications*, vol. 15, no. 7, pp. 558–565, Jul. 2020, doi: 10.12720/jcm.15.7.558-565

[17] M. Tayyab, X. Gelabert, and R. Jantti, "A survey on handover management: From LTE to NR," *IEEE Access*, Institute of Electrical and Electronics Engineers Inc., pp. 118907–118930, 2019. doi: 10.1109/ACCESS.2019.2937405.

[18] H. Yu, L. Chen, and J. Yu, "Network selection algorithm based on chi-square distance in heterogeneous wireless networks," *Wireless Personal Communications*, vol. 111, no. 3, pp. 1625–1643, Apr. 2020, doi: 10.1007/s11277-019-06946-2

[19] D. Das, "An efficient algorithm for fast handoff in wireless mobile networks," *Wireless Personal Communications*, vol. 116, no. 4, pp. 3491–3501, Feb. 2021, doi: 10.1007/s11277-020-07861-7

[20] S. M. Hussain and K. M. Yusof, "Dynamic q-learning and fuzzy cnn based vertical handover decision for integration of dsrc, mmwave 5g and lte in internet of vehicles (Iov)," *Journal of Communications*, vol. 16, no. 5, pp. 155–166, 2021, doi: 10.12720/jcm.16.5.155-166

[21] S. Alam, S. Sulistyo, I. W. Mustika, and R. Adrian, "Handover decision for v2v communication in vanet based on moving average slope of rss," *Journal of Communications*, vol. 16, no. 7, pp. 284–293, Jul. 2021, doi: 10.12720/jcm.16.7.284-293.

[22] M. B. Patil and R. Patil, "Fuzzy based network controlled vertical handover mechanism for heterogeneous wireless network," *Materials Today: Proceedings*, Jul. 2021, doi: 10.1016/j.matpr.2021.06.364.

[23] M. R. Palas, *et al*., "Multi-criteria handover mobility management in 5G cellular network," *Computer Communications*, vol. 174, pp. 81–91, Jun. 2021, doi: 10.1016/j.comcom.2021.04.020

[24] R. Kaur and S. Mittal, "Handoff parameter selection and weight assignment using fuzzy and non-fuzzy methods," in *Proc. International Conference on Secure Cyber Computing and Communications*, May 2021, pp. 388–393, doi: 10.1109/ICSCCC51823.2021.9478179

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