Vertical Handover Decision Making Algorithms for 5G Heterogeneous Networks: A Review

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Abstract—The wireless networks have been rapidly used in our daily lives, especially mobile wireless networks. An environment consisting of several networks such as WLAN, 4G-LTE, and 5G, is known as a heterogeneous network. Wireless networks are widely used to support various data services such as live video streaming, upload data, download data and cloud service depending upon their capacity and nature. When the mobile terminal is moving, the network availability will be changed. Therefore, the mobile terminal must perform handover from one network to another network in heterogeneous networks to maintain the call and quality of service (QoS). This process is known as Vertical Handover (VHO). A seamless handover is important to provide uninterrupted high quality service while performing the handover. To achieve this, various vertical handover decision making algorithms have been proposed and studied using advanced tools and proven concepts. This paper gives an overview of current research on handover decision making in fifth generation (5G) heterogeneous wireless networks.

Keywords—Vertical Handover Decision Making, Heterogeneous Networks, Quality of Service, 5G, Seamless Handover

I. INTRODUCTION

In this fast-paced evolution era of wireless and mobile networks, seamless handover from one wireless technology to another different wireless technology is essential to guarantee the mobile terminal is always connected to the internet. A seamless handover is a process of ensuring uninterrupted service while the mobile terminal is switching from one network to another different network, such as 4G Long-Term Evolution (LTE), 5G, Wireless Fidelity (WiFi), Worldwide Interoperability for Microwave Access (WiMAX) and Universal Mobile Telecommunications System (UMTS). The handover process can be grouped into horizontal and vertical handover. A horizontal handover or intra-system handover is the process of migrating from a base station (BS) to another BS within the same network technology, such as handover between two geographically neighbouring BS of a 5G network.

On the other hand, vertical handover or inter-system handover is switching between two different network technologies, for example, handover from Wireless Local Area Network (WLAN) or WiFi to 5G cellular network.

The horizontal handover process is more straightforward than the vertical handover process because it only involves a single wireless network technology. A mobile terminal (MT) can choose the best base station (BS) by comparing the Received Signal Strength (RSS) from different BS. The handover is necessary if the RSS of the serving BS falls below the threshold. On the other hand, the vertical handover cannot make a handover decision based on a single RSS criterion because the RSS of different wireless technologies cannot be compared directly. The vertical handover process requires more handover criteria such as network bandwidth, power consumption, security, cost, and user preference for handover decision making.

The vertical handover can be either optional or mandatory. The handover is optional when the serving network fulfils the services requirements and other better alternative candidate networks are available. The optional handover could be performed to improve user satisfaction in terms of cost-saving, power consumption, and some other factors. Conversely, the handover is necessary when the RSS of the serving network is below the predefined RSS threshold, or network quality is incapable of meeting the service requirement and other alternative candidate networks are available. The mandatory handover decision is taken to prevent link breakdown and maintain the service quality at an acceptable level.

II. CLASSIFICATION OF HANDOVER

Figure 1 shows the types of handovers. The horizontal handover is performed between the BS within the same wireless technology (homogeneous network) to let mobile terminals maintain the connection and service quality, such as from 5G BS to another 5G BS [1]. The vertical handover is the handover process between two different types of networks, for example, handover from WiFi to LTE.

International Journal of Emerging Technology and Advanced Engineering

Website: www.ijetae.com (E-ISSN 2250-2459, Scopus Indexed, ISO 9001:2008 Certified Journal, Volume 12, Issue 01, January 2022)

In the field of heterogeneous networks, vertical handover is necessary. The MT could handover to another network for a better data rate or bandwidth. Figure 2 shows the horizontal and vertical handover in the heterogeneous wireless network [2].

Figure 1 Types of handovers [1]

Figure 2 Vertical and horizontal handover [2]

The handover led by the mobile is often called Soft Handover. In this phase, the connection to the new network is created before disconnecting the link of the serving network. This mode is also called "make-before-break". Figure 3 shows the soft handover mechanism where the Radio Network Controller (RNC) is used to control every node that is connected to it. The RNC can perform radio resource management, mobility management and encrypts the data before sending it to the mobile [3].

Hard handover is the serving network connection break before the new network is established. This mode is also called "break before make". An interruption occurs when the MT performs the hard handover process, as shown in Figure 4.

Figure 3 Soft handover Mechanism [3]

Figure 4 Hard handover Mechanism [3]

Network-controlled handoff (NCHO): The network decides whether the handover should be initiated or rejected. The mobile terminal initiates the handover. It scans for available networks and selects a new network that is considered as the best. Then the network will decide to accept or reject the handover.

Mobile-controlled handoff (MCHO): In this case, the handover is determined by the MT based on the handover criteria such as Radio Signal Strength (RSS), user preferences, mobile speed, etc. The handover would help with the service quality parameters given by the network, such as packet loss rate and bandwidth. The mobile terminal is fully in control of the handover process.

Mobile-Assisted handoff (MAHO): The network makes the handover decision based on the data provided by the mobile terminal. The mobile terminal continuously collects the network information from the neighbouring BS and sends the report to the BS for handover decision making.

III. MEDIA INDEPENDENT HANDOVER

The inter-network handover requires an interface between different network link-layer. Media Independent Handover Function (MIHF) located between the link layer and network layer act as an intermediate layer between upper and lower network layers. This standard can communicate with all kinds of IEEE networks. The same goes for mobile networks such as LTE, UMTS, GPRS, etc. Figure 5 shows the MIHF architecture [4].

Figure 5 MIHF architecture [4]

IV. PROCESS OF VERTICAL HANDOVER

Vertical handover is an operation that allows an MT to switch from one network to another network without losing the connection. Figure 6 shows that the handover process can be categorized into three stages [1].

Figure 6 Handover process [1]

In the first stage, the MT scans for available networks and reads the main attributes of the available networks such as signal strength, bit error rate and level of interference.

Apart from these, MT moving speed, service requirements and terminal performance are also important criteria for handover decision making. All this information will be used in the handover decision stage.

The handover decision would be the most critical stage of the entire process. The quality of service (QoS) may be diminished by an improper handover and even disrupt the communication in progress. This phase will track the currently connected network quality and compare it with the new incoming network if it is necessary to perform the handover. The selection strategy is to choose the best network for the MT by considering user preferences, service requirements and characteristics of the available network. The last stage is to switch the network toward the targeted network. It connects to the selected network and releases the serving network.

The authentication service allows MT to roam through several access points seamlessly and safely. Figure 7 shows the handover authentication service [5]. MT registers with the server and connects to an AP to access the subscribed services. Handover authentication should be conducted at the new AP when the MT moves from the serving AP into the new AP. Through handover authentication, AP2 authenticates MT to deny any access request from an unauthorized user. A session key between the MT and AP2 should also be established to protect the data exchanged over the subsequent connection.

Figure 7 Handover Authentication Service [5]

V. VERTICAL HANDOVER DECISION MAKING CRITERIA

Handover parameters are the specifications that are analyzed to indicate handover necessity and choose an optimum available network. The handover judgment criteria in the network selection process can be subjective or objective to reduce or optimize nature. These criteria can be classified into four groups [6].

International Journal of Emerging Technology and Advanced Engineering

Website: www.ijetae.com (E-ISSN 2250-2459, Scopus Indexed, ISO 9001:2008 Certified Journal, Volume 12, Issue 01, January 2022)

A. Network-related criteria

It is the technical characteristics and efficiency of the radio access networks. These criteria are based on the network, for example, cell coverage, connection quality and capacity, throughput, load, etc.

B. Terminal-related criteria

It is related to the characteristics and current condition of the mobile terminal. For example, supported interfaces, speed, hardware performance, location-based information, energy consumption, etc.

C. Service-related criteria

The service requirements are closely linked with the QoS parameters like delay, jitter, error ratio, and packet loss ratio. These parameters are widely used in the QoS based handover schemes.

D. User-related criteria

These criteria are related to the user's expectation or satisfaction, such as the user profile and preferences, service costs, quality of experience, etc., such criteria are usually represented in linguistic terms.

VI. HANDOVER PARAMETERS

A. Received Signal Strength (RSS)

RSS is the most selected criterion in the handover decision making. There is a close relationship between RSS readings and the distance from the MT to its point of attachment [6]. In horizontal handover, RSS represents the link quality. The higher the RSS value better the signal quality.

B. Available bandwidth

It is the most used indicator of traffic efficiency. The maximum theoretical bandwidth is very tightly correlated to the capability of the link. It would improve QoS by switching to a network with better conditions and higher performance.

C. Security level

Within a security profile, the security level is information that is used to define if data can be transmitted through another network. There will be a higher encrypted network scheme chosen.

D. Cost of service

Service cost can significantly vary from one internet service provider to another provider but in a different network environment.

It also has a close relationship with the available bandwidth and QoS levels. This can affect the user decision on which network to choose in a heterogeneous networking environment.

E. Handover Latency

The time span between the transmission or reception of its last IP packet through the previous access router and the first packet from the new access router is called handover latency. Handover latency plays a very important role in interactive cellular applications which could be notably dissimilar between different technologies.

F. Power Utilization

When the mobile terminal battery is running low, it becomes critical. In this kind of situation, a handover should focus on the power saving network to help prolong the life of the battery.

G. Network Connection Time

This is a time for the mobile terminal to stay connected to the particular network. Predicting network connection time is essential for opting the next handover initiation and maintaining QoS at a satisfactory level. If a handover happens too rapidly, it can result in network resources being wasted and handover failure.

H. User Personal Preference

Users can select a preferable network over the other candidate network for certain network access.

VII. VERTICAL HANDOVER DECISION MAKING ALGORITHMS

An analysis of various vertical handover decision making (VHD) algorithms is discussed in this section. We categorized the handover algorithms into three categories which are RSS-based, multi-attribute based and combination-based handover schemes.

A. RSS Based Handover Scheme

Dwell Timer based Handover Decision Making Scheme: The handover decision scheme proposed by [7] and [8] predicts the travelling distance in a WLAN cell coverage area based on the variation of RSS values. Figure 8 shows the handover scheme that uses the travelling distance prediction technique.

Figure 8 Flowchart of Travelling Distance Prediction based handover scheme [7]

The relationship between the RSS and the distance between the AP and MT at point p inside the WLAN coverage area can be calculated by using the path loss model in Equation (1).

$$RSS_p = E_t l_{OP}^{-\beta} 10^{\frac{\xi}{10}} \quad (1)$$

where E_t is the transmit power of the AP, β is the path loss exponent and ξ is a Gaussian distributed random variable with a mean of zero and a standard deviation up to 12dB. l_{OP} represents the distance between point p and the AP. The advantage of this approach is that it reduces the handover failure rate as MT travels at the speed of 30 km/h and above. The main drawback of this work is the authors assumed that the MT travels in uniform velocity in the WLAN coverage.

Hussain *et al.* [8] proposed a handover necessity estimation (HNE) algorithm to minimize the number of handover failures and unnecessary handover while MT traverses a WLAN cell. It presented a new model for estimating dwell time in WLAN cells.

The RSS values at points P_1 and P_2 (as shown in Figure 9) are obtained to predict the dwell time in a WLAN cell. P_i and P_o in Figure 9 denote the point where the MT enter and exit from the WLAN cell, respectively. The algorithm has preserved both the handover failure and unnecessary handover rates at the desired level. Figure 10 shows the flowchart of the HNE method. However, the scheme showed that the unnecessary handover and handover failure rate increased as the speed of MT increased.

Figure 9 VHD geometrical mode

Figure 10 Flow Chart of Handover necessity estimation (HNE) method

Mahmood *et al.* [9] proposed a new handover mechanism to improve the imperfections of the handover schemes presented by [7] and [8]. The proposed mechanism estimates handover necessity by predicting the dwell time using consecutive RSS measurements in WLAN cells. The algorithm assumes that the WLAN cell has a circular contour and the mobile terminal traverses the WLAN cell at uniform velocity and straight line. The dwell time prediction scheme formula is shown as Equation (2).

International Journal of Emerging Technology and Advanced Engineering

Website: www.ijetae.com (E-ISSN 2250-2459, Scopus Indexed, ISO 9001:2008 Certified Journal, Volume 12, Issue 01, January 2022)

$$t_n = \frac{R^2 - l_{CZn}^2 + v^2(t_{Zn} - t_A)^2}{v^2(t_{Zn} - t_A)} \quad (2)$$

where t_n denotes the dwell time of the network, l_{CZn} is the distance of entrance point A and the central point M. t_{Zn} and t_A is the sampling time at point Z_n and entry point A, respectively. v denotes the velocity of MT. Figure 11 shows the dwell time prediction scenario in the WLAN cell. It is presumed that the mobile terminal receives a considerably strong signal at point A, while signal strength lowers from point B. Point M is the middle point of the MT travelling path.

Figure 11 Travelling Time Prediction Scenario in a WLAN Cell

Though the mathematical expression proposed by [9] and [8] is nearly similar. The simulation results show that the number of unnecessary handovers can be kept at the desired level. The total number of unnecessary handovers is lower with an increase in MT velocity compared to [7] and [8] mechanisms. However, this scheme has a limitation where authors assume that MT moves at a constant velocity. But, this limitation has been overcome by Yew *et al.* [10][11].

RSS Based Adaptive Hand-Off Management Scheme in Heterogeneous Networks: A handover decision making based on the type of network in which it currently resides and the one with which it attempts to handover by some predefined rules was proposed by [12]. The handover depends on a few factors such as the velocity of the MT, latency of the handover process, type of network the MT is currently using, type of network which MT is trying to initiate handover and the coverage size of the cellular network, WLAN or High-Performance Radio LAN (HIPERLAN) cell the MT is currently residing.

Figure 12 shows the handover scheme based on the RSS value where x_1 is the distance between MT and Base Station 1 (BS1) and x_2 is the distance between MT and Base Station 2 (BS2). When MT was moving toward the BS2, the BS1 RSS value decreased. The handover is initiated if the RSS value is less than the threshold value. Assume MT is initially connected to BS1 and trying to handover to a BS2. The handover will only initiate when the RSS of BS2 is greater than the threshold.

Figure 12 Handover scheme based on RSS value

MT is not initiating handover in this algorithm if the RSS value is lower than the RSS threshold level. The results of this scheme showed that the RSS threshold changes depending on network types and MT velocity. The threshold value is inversely proportional to the velocity of the MT. The drawback of this scheme is that the number of unnecessary handovers increases when the velocity of MT increases.

RSS based on link quality parameters for heterogeneous wireless networks: Ahjuha *et al.* [13] proposed a VHD algorithm that determines the best available wireless network while preserving the multimedia service quality of service (QoS) in heterogeneous wireless environments. The handover parameters used for the network selection are RSS, distance and outage probability. If the network has high average RSS values and the probability of outage is less than other networks, that network will be selected as a handover target. The flowchart of the handover algorithm is shown in Figure 13.

The algorithm improved the network selection with less overhead and burden on the mobile terminal compared to the conventional method.

By using the outage probability and averaged RSS in the overlapped region of the heterogeneous environment, the efficiency of the handover has improved. It fulfilled the need for a decision on network selection that introspects the requirements of the application and retains the dynamic connection during the handover by engaging the make-before-break approach. However, this scheme only focused on 2G and 3G. The handover performance will degrade in the 5G network, especially in a high mobility scenario because 5G cell is much smaller than preceding networks.

B. Multi-Attribute based Handover Scheme

Multi-attribute-based handover scheme in Telemedicine: Bhat *et al.* [14] proposed a Dynamic Media Selection (DMS) based handover algorithm between WiFi and LTE in telemedicine scenarios. The DMS algorithm showed the best use of the channel to efficiently transmit the biosignal by offloading the procedure between WiFi and LTE. This optimal media selection is a quick process that remains active until the source reaches the destination. The RSS and SNR parameter values were measured and compared with their threshold values. This algorithm works for the always best connection provision of service. The RSS value of each network can be obtained by using Equation (3).

$$RSS = \text{Transmit power} + \text{Antenna gain} - \text{Path loss} \quad (3)$$

The results demonstrate that both network WiFi and LTE with different node densities have reduced the delay in transmitting the packets from the source to the destination. In addition, with the increase of nodes, the throughput decreases.

Figure 13 Handover algorithm proposed in [13]

International Journal of Emerging Technology and Advanced Engineering

Website: www.ijetae.com (E-ISSN 2250-2459, Scopus Indexed, ISO 9001:2008 Certified Journal, Volume 12, Issue 01, January 2022)

Mukhopadhyay *et al.* [15] proposed a multi-attribute based algorithm to improve the algorithm presented in [14]. The LTE and WiFi wireless technologies are considered in the proposed scenario. The handover parameters used in this algorithm contains RSS, SNR, power consumption, delay, bandwidth. The authors assumed only the LTE network is available in rural areas. The mobile terminal uses the LTE network to transfer data from rural area. If both WiFi and LTE are available, the mobile terminal will select the network with the highest Network Quality Value (NQV), where the NQV value can be obtained using Equation (4). If the WiFi is not available, the mobile terminal will continue with LTE.

$$NQV = \sum n_{ij} \quad (4)$$

where n_{ij} is the normalized value of each attribute. The algorithm aims to provide constant data transmission. Unfortunately, this algorithm does not take the MT velocity into account and it will lead to high unnecessary handover in 5G small cell networks, especially in wireless mobile communication environments. Figure 14 shows the flowchart of this algorithm.

Figure 14 Multi-Attribute based handover scheme in Telemedicine

Yew *et al.* [16] proposed a telemedicine-based handover decision making (THODM) algorithm that transfers the patient health data to the healthcare centre by selecting the best wireless network based on the user preference, service requirements and speedometer. Parameters used in this algorithm were RSS, SNR, data rate, cost, and MT velocity. The speedometer is used to obtain the MT velocity. The THODM algorithm applied the dwell time prediction scheme, Equation (5), to estimate the dwell time in the small cell networks.

$$T = \frac{R^2 - r^2 - d^2}{dv} \quad (5)$$

where R denotes the radius of the AP, r is the radius of AP and Predefined RSS threshold. d represents MT travelling distance from the boundary of AP coverage and predefined RSS threshold line. v is the velocity of the MT.

The predefined dwell time threshold is set to 2 seconds. If the predicted dwell time, T , for MT to traverse the network is less than 2 seconds, the network will be rejected, and no handover will be initiated. Only the networks with the estimated dwell time greater than the threshold will be proceeded for network quality evaluation and ranked. Figure 15 shows the scenario of MT traversing the small cell network and Figure 16 shows the flowchart of the THODM scheme. The network candidate with the highest score will be selected as a handover target. The best network can be obtained by using Equation (6), where Q_k is the quality function of each network candidate and B is the best network to initiate handover.

$$B = \max(Q_k) \quad (6)$$

The algorithm proposed by the authors has reduced the unnecessary handover rate in a high-speed environment. This algorithm is more cost effective and provides higher throughput than the conventional handover schemes.

Figure 15 MT trajectory within small cell network

Yew *et al.* [17] proposed an Improved-TOPSIS (I-TOPSIS) based handover for telemedicine applications. TOPSIS approach is used because of its multi-attribute decision analysis method that simultaneously estimates both the best and worst alternatives. Network-based handover criteria chosen for this algorithm are divided into two categories: QoS-based and non-QoS based. QoS based criteria consist of delay, throughput, and packet error rate, while the non-QoS based criteria are power usage and cost. The I-TOPSIS handover algorithm reacts differently toward the patient health conditions. The algorithm will ignore the user setting and priorities the high-quality network to enhance the service quality while the patient is in critical situations. The weight allocation for QoS based criteria can be calculated by Equation (7).

$$W_j = \frac{(w_j^*)^H}{n^h} \quad (7)$$

where w_j^* denotes the assigned weight by the user to criterion j . H denotes patient health condition in binary where one (1) stand for patients in non-critical condition and zero (0) represents a critical condition. n denotes the number of QoS based criteria and h represents the complement of H . Figure 17 shows the general flowchart of the I-TOPSIS handover algorithm. The weight of the non-QoS based criteria can be obtained by using Equation (8).

Figure 16 Flowchart of THODM scheme

Figure 17 Network selection based on user health conditions [17]

$$W_j = Hw_j^* \quad (8)$$

The proposed algorithm has improved user satisfaction. The algorithm can be further improved by combining the prediction algorithm proposed in [10] to reduce the unnecessary handover in high dense 5G networks.

C. Combination based Handover Scheme

Yew *et al.* [18] proposed a Robust and Fast Vertical Handover (RFVHO) algorithm for Telecardiology application that aims to always connect to the best network candidate in heterogeneous wireless networks. MIH is used for the interoperability between heterogeneous networks. MIH enables handover in heterogeneous networks with no perceptible interruption to an ongoing video or voice conversation. The algorithm searches for all available networks when the RSS of the serving network falls below the predefined threshold value. This algorithm uses Fuzzy Logic to select the most appropriate network among the available network candidates. MT monitors the RSS, velocity and user bandwidth requirement as shown in Table 1 regularly to ensure no handover is performed while the current network is still appropriate to the user requirement. The network quality, Q_k , can be evaluated by using Equation (9).

$$Q_k = F(RSS_k - RSS_{Tk}) \times F(B_k - B_{req}) \times F(V_k - V_{MT}) \quad (9)$$

where RSS_k is the RSS of network k , RSS_{Tk} denotes the threshold for network k , B_k is the bandwidth of network k , B_{req} is the user bandwidth requirement, V_{MT} denotes MT velocity and V_k is the maximum velocity support by network k . Network k can be WLAN, UMTS or WiMAX.

TABLE 1
BANDWIDTH REQUIREMENT FOR TELECARDIOLOGY

Services	Bandwidth
Video	640 – 5000 kbps
Audio	32 – 256 kbps
ECG	24 kbps/12leads
Vital Signs	2 – 5 kbps

This algorithm showed a lower handover rate and no ping-pong effect or unnecessary handover occurred. The RFVHO algorithm can select the most appropriate network quickly and robustly. However, the authors only consider MT moving at a constant velocity of 20m/s. The handover parameters such as security and cost can be considered in this work to further improve user satisfaction.

Ben *et al.* [19] proposed three different Fuzzy based handover algorithms: Fuzzy-SAW, Fuzzy-TOPSIS and Fuzzy-VIKOR. In dealing with imprecise data and numerous handover criteria, these algorithms harness the strength of Fuzzy Logic and multi-attribute decision making (MADM) method for intelligent decision making.

The handover parameters used for handover decision making are RSS, delay, MT velocity, data rate, and power.

The Simple Additive Weighting (SAW) method is the simplest MADM method used for decision making. Equation (10) is the SAW formula used to obtain the overall score by computing the sum of all weighted attribute values.

$$C_{SAWi} = \sum_{j=1}^n a_{ij} w_j \quad (10)$$

where n is the number of context criteria, a_{ij} is context criteria j of the candidate network i and w_j is the weight of criteria j .

TOPSIS is widely used in the MADM process. An ideal solution can be calculated using Equation (11).

$$C_{TOPSISi} = \frac{d_i^-}{d_i^+ + d_i^-} \quad (11)$$

where d_i^+ and d_i^- denote the positive and negative ideal solutions of network candidates, respectively.

VIKOR is a method of MADM used to evaluate the best solution for different attributes. The concept is to provide the best solution to a given problem by computer utilities and alternative measures of regret. The C_{VIKOR} can be obtained using Equation (12).

$$C_{VIKORi} = \arg \min_{i \in m} \vartheta \left[\frac{S_i - \min S_i}{\max S_i - \min S_i} \right] + (1 - \vartheta) \left[\frac{R_i - \min R_i}{\max R_i - \min R_i} \right] \quad (12)$$

where ϑ represents the weight of the maximum group utility (0.5), S_i denotes the utility measurement and R_i represents the regret measurement computed.

The algorithms are simulated in a multi-radio access terminal environment. All these three algorithms reduce the decision delays. However, the authors assumed MT remains at a constant speed while traversing the networks.

Mathonsi *et al.* [20] proposed an intelligent based intersystem handover algorithm by incorporating grey prediction theory (GPT), Fuzzy Analytic Hierarchy Process (FAHP) and Principal Component Analysis (PCA), which aims to lower the handover latency. GPT is used to estimate the proper handover time by predicting the RSS value. The RSS prediction formula is expressed as Equation (13).

$$PRSS^0 = (n + 1) = (RSS^0(1) - \frac{b}{c})e^{-cn} (1 - e^c) \quad (13)$$

where c is the development grey number and b are the internal control grey number. RSS^0 is the received signal strength of the network.

International Journal of Emerging Technology and Advanced Engineering

Website: www.ijetae.com (E-ISSN 2250-2459, Scopus Indexed, ISO 9001:2008 Certified Journal, Volume 12, Issue 01, January 2022)

Intersystem handover is initiated if the serving base station (SBS) RSS level is below the threshold and the target base station (TBS) predicted received signal strength (PRSS) level is greater than the SBS level.

The FAHP and PCA can reduce the inaccurate network selection and the handover algorithm becomes more adaptive to user preferences. PCA acquires the QoS factor by processing the weighted decision matrix and the network with the highest QoS factor will become the handover target. The QoS factor can be determined using Equation (14).

$$QoS_k = \frac{\sum_{i=1}^k \lambda_k}{\sum_{j=1}^m \lambda_m} \quad (14)$$

where k is a linearly independent principal component used to replace the m original attributes and λ_k is the eigenvalues of the covariance matrix.

Almutari *et al.* [21] proposed a Genetic algorithm (GA) based handover scheme. In many fields of science and engineering, GA has been adapted effectively for many applications. These algorithms can be used to solve different types of optimization problems, depending on the principles of natural selection and genetics. The GA solution is to address the issue of weight optimization to minimize rating abnormalities in vertical handover applications. The process can be divided into five steps as shown in Figure 18. This algorithm has successfully reduced the rating abnormality for SAW by 24.5% and TOPSIS by 32.5%.

Figure 18 Genetic Algorithm process

Chattate *et al.* [22] proposed a Fuzzy Enhanced-TOPSIS based handover decision-making algorithm that considers each access network throughput, data rate, jitter, latency, and battery. The Fuzzy Enhanced-TOPSIS (FE-TOPSIS) method first construct a decision matrix where each row i corresponds to an available network ($A_1, A_2, A_3 \dots$) and each column j corresponds to a different criterion ($C_1, C_2, C_3 \dots$). Then, assign the weight fitting to each criterion by using the Fuzzy analytic hierarchy process (FAHP) method. After that, calculate the performance of each network by using the Fuzzy Enhanced-TOPSIS algorithm and rank the alternatives by sorting the value of relative closeness, C_i , in descending order. The value of relative closeness to the ideal solution is expressed in Equation (15), where μ_1 and μ_2 are relative importance. S_i^+ and S_i^- refer to the distance of each alternative from the ideal positive solution (FPIS) and ideal negative solution (FNIS).

$$C_i^{Proposed} = 1 - \frac{\mu_1 * S_i^+ + \mu_2 * S_i^-}{S_i^+ + S_i^-}, \quad i = 1, \dots, n \quad (15)$$

In this method, the authors managed to reduce the number of handovers compared to the Fuzzy-TOPSIS algorithm. In addition, this FE-TOPSIS approach is capable of evaluating the best network with a lower handover latency.

Tan *et al.* [23] proposed a Multi-Attribute and Neural Network Handover Algorithm for heterogeneous networks with UMTS, GPRS, WLAN, 4G and 5G. Every network has neural network models of its three-layer Back Propagation (BP). Each layer's neuron weight is determined by the values of maximum transmission rate, minimum delay, SINR, bit error rate, user moving speed, packet loss and download rate of the network. MT gathers all the weights and inputs the values to the five respective qualified neural network models. The forecast values of the network download rates are obtained for each of the five network types and the network with the highest score is chosen as the target handover network. Figure 19 shows the flow diagram of the implementation of the handover scheme. The results show that the switching times increase when the download rate of the network drops.

Figure 19 Flow diagram of the Multi-Attribute and Neural Network

Dipha et al. [24] presented an algorithm that is a no-pairing authentication mechanism and provides users on the wireless network with security and privacy. This mechanism consists of two primary steps, the pre-deployment phase and the authentication phase. The pre-deployment phase initializes and creates an initial architecture for possible handover and authentication procedures. The initialization process is carried out by the authentication server (AS). In the handover authentication phase, MT initiates the vertical handover process if the network does not accept the user's request. Mutual authentication is obtained between the MT and new connection point. It is possible to release and build a peer-to-peer transient key directly upon authorization.

Several e-health users and a set of cellular networks defined as critical and non-critical conditions for remote health monitoring of cardiac patients are considered in this algorithm.

The state of network traffic, such as direct storage and real-time, would be selected based on the circumstances. Medical information is collected from patients and then transmitted to the medical facility over a wireless network such as WiFi, UMTS, and WiMAX. The user health condition is considered as one of the metrics in this scheme. The algorithm monitors the serving network quality and user moving speed on a regular basis. When the serving network cannot meet the service requirements, the Trust and Privacy Multiple Attribute Vertical Transfer algorithm (TPMVHO) searches for nearby available networks that meet user requirements. The parameters weight value is determined based on the user health condition.

The hybrid genetic metaheuristic with cuckoo search (GA-CS) algorithm increases the performance efficiency and has greater flexibility to resolve larger-scale problems to find optimum attribute weight values. The Intuitionistic Fuzzy TOPSIS algorithm ranks the alternative networks with the obtained weight values. This approach is capable of reducing delays by spreading computational activities across the accessible visitor network. The algorithm has reduced the number of handovers by 25.3%. This algorithm can also minimize abnormal ranking problems in the TOPSIS method and ensure a smooth and seamless connection. This algorithm can be further improved by considering cost and power consumption as input parameters to increase user satisfaction.

Diong *et al.* [25] presented a Fuzzy-TOPSIS based handover algorithm. The fuzzy approach is used to overcome the limitation of MADM, which cannot process uncertain and imprecise data within criteria. This algorithm combines the advantages of both algorithms, which are multi-criteria based, process uncertain input data and weight value to obtain the optimal decision. The Fuzzy AHP approach is implemented to process the parameters weight value and parameters for TOPSIS. The parameters used in this algorithm consist of RSS, bit error rate, SNR, cost, delay, packet loss and data rate.

Firstly, the Fuzzy-TOPSIS handover algorithm builds a decision matrix for each network candidate concerning its criteria. Next, the weight value is obtained by using Equation (16).

$$w_i = \left(\frac{l+m+u}{3} \right) \quad (16)$$

where l , m and u denotes the lower bound value, mid-value and upper bound of the triangular fuzzy number based on Satty's AHP scale.

International Journal of Emerging Technology and Advanced Engineering

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Weight values are set based on the user preference using linguistic terms. After that, the TOPSIS algorithm transforms different scales and units among various criteria into common measurable units to allow comparisons across all the criteria. Lastly, Equation (11) is used to calculate the relative closeness of each network to find the best network

for handover. This algorithm is able to minimize unnecessary handover and ping-pong effects effectively.

VIII. SUMMARY OF OVERALL VHD SCHEMES

Table II summarise the strengths and weaknesses of the reviewed VHD schemes.

TABLE II
SUMMARY OF VHD SCHEMES

Categories	VHO	Strengths	Limitations
RSS based	Dwell Time [7]–[10], [26], [27]	a) Minimize the number of handover failures and unnecessary handovers	a) Assume MT traverse the network at constant velocity.
	RSS threshold [12], [13]	a) Reduce the network selection delay and network selection rate b) Simple	a) Handover failures increase when the MT velocity increases b) Only suitable for homogeneous network
Multi-Attribute based	Dynamic media selection [14], [15]	a) Low handover rate b) Reduce the number of unnecessary handovers c) Provide constant data transmission	a) Low throughput when the number of nodes increases
	THODM [16]	a) Reduce the number of unnecessary handovers b) High throughput c) Cost-effective	a) Assume MT moves at a constant speed
	I-TOPSIS [17]	a) Reduce the number of unnecessary handovers b) High QoS	a) Induce a high handover rate if MT moves at high speed in a high dense small cell network.
Combination based	RFVHO [18]	a) Network quality fulfils user requirements b) Low handover rate c) Reduce ping-pong effect	a) Assumed MT moves at constant velocity
	Fuzzy Logic with MADM [19]	a) High throughput b) Reduce delay time c) Multi-criteria	a) High power consumption b) High handover delay if more criteria take into account.
	Intersystem handover [20]	a) High throughput b) Reduce erroneous network selection	a) MT velocity does not consider b) High power consumption
	Genetic approach with MADM [21]	a) Reduce ranking abnormalities	a) High complexity, will increase handover latency
	Fuzzy-TOPSIS [22]	a) Multi-criteria b) Low number of handovers c) Low handover delay	a) More complex than MADM schemes
	Multi-attribute and Neural network [23]	a) High handover success rate	a) High complexity, will increase handover latency b) Test at low-speed environment only
	Trust and Privacy based [24]	a) Reduce blocking rate b) High throughput c) Reduce the number of handovers	a) High complexity, will increase handover latency
	Fuzzy-TOPSIS based Optimal VHO algorithm [25]	a) Reduce unnecessary handover b) Reduce ping-pong effect	a) High complexity, will increase handover latency

International Journal of Emerging Technology and Advanced Engineering

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IX. CONCLUSION

Due to rapid progressions in network technologies, more efforts are needed to get seamless connections such as live stream, transfer big data, and cloud services. In this paper, we reviewed various vertical handover decision-making algorithms. The vertical handover decision making algorithms are categorized into three groups and analyzed their strengths and weaknesses in terms of criteria, complexity, and selection methodology. This research field has been used in several commodities and field tests for extended over a long time now. However, truly achieving the seamless connection has not yet been placed in daily life even though this study has been here for so long.

The vertical handover algorithm is either insufficient use of network parameters or lacks the detail to be tested in real-environment situations to gain more studies. Therefore, this field of research is still a challenging area and open issue. The most difficult part is formulating a handover algorithm that can be used in a high dense 5G network. High dense 5G network is more challenging than preceding networks because its cell coverage is much smaller.

In the future, the internet is getting more evolved to be used and more applications are needed to learn more about network conditions to work correctly and efficiently alongside seamless connectivity. Therefore, a common infrastructure is needed to achieve seamless handover.

Acknowledgement

This research is supported by the Ministry of Higher Education (Kementerian Pengajian Tinggi) Malaysia, Fundamental Research Grant Scheme FRGS/1/2020/TK0/UMS/02/2, Universiti Malaysia Sabah Grant SGI0113-2020 and SGI0138-2020.

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