Performance Analysis of Multi-level Vertical Handover in Wireless Heterogeneous Networks

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Abstract The quest for high data rates, mobility and QoS has witness the integration of diverse wireless network systems in providing services to mobile users anywhere and at all-time. The convergence of these networks makes it possible for the mobile user equipment to roam seamlessly across the heterogeneous networks with session continuity. However, the integration comes with its own difficulties of selecting the right target network to handover to and therefore requires the right decision to achieve such task. This paper attempts to describe multi-level vertical handover decision algorithm that employs multi-attribute decision making in selecting the best network to optimize the VHO. The algorithm considers received signal sensitivity (power level or RSS), bandwidth and cost as the deciding factors in selecting the correct network based on the established memberships (function and degree) of the processed correlated weight vector. The results of the simulation show how the vertical handover optimization could be realized by selected the right target network.

Keywords eNodeB · Fuzzy inference system · VHO · Bandwidth · Cost · Sensitivity

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1 Introduction

The high demand of data rates, speed, capacity and the paradigm of "always best connected" or "ABC" by users of mobile devices has witnessed in recent times, a significant increase in application services from new generations of communication (smart phones, iPods, tablets, gaming devices, etc.) devices. To fulfill these requirements, there is the need to integrate numerous wireless interfaces to complement each other because of the similarity in the network characteristics. Recent developments [1–3] have shown that cellular networks based on the 3GPP standards (LTE/LTE-advanced) and IEEE standard (IEEE802.16x) can coexist to achieve seamless operation when mobile user equipment (UE) roam. Vertical handover, a term used to describe the switching from one network to another of diverse technologies, is a scheme where seamless vertical handover between different network technologies are considered as demonstrated in Fig. 1. The main purpose of vertical handover is to achieve continuous service for mobile users, but this has become an issue in heterogeneous wireless networks since each of these technologies has their own mobility management solutions which poses a major challenge to be tackled.

The services of mobile UE that crosses the cell boundaries of different systems while roaming are supposed to be seamless with a guaranteed QoS and without disruption. This process of Inter-system switching is known as vertical handover (VHO). The VHO decision algorithm as presented here is the combination of fuzzy logic (FL) and multi-attribute decision making (MADM) systems to form fuzzy MADM that is hinged on three metrics (sensitivity, cost and bandwidth) as input parameters.

The rest of the paper is as follows; Sect. 2 reviews related works, while Sect. 3 discusses the membership functions of the input parameters. In Sect. 4, the weight vector for the input parameters and their membership degrees for every BS were computed to achieve the values of the vertical handover decision of each eNodeB. Section 5 describes the proposed multi-level vertical handover decision algorithm (MLVHDA) scheme based on these values. Performance evaluation of the algorithm is done by simulation and comparing the results with others found in other literatures as presented in Sect. 6, while Sect. 7 concludes the paper.
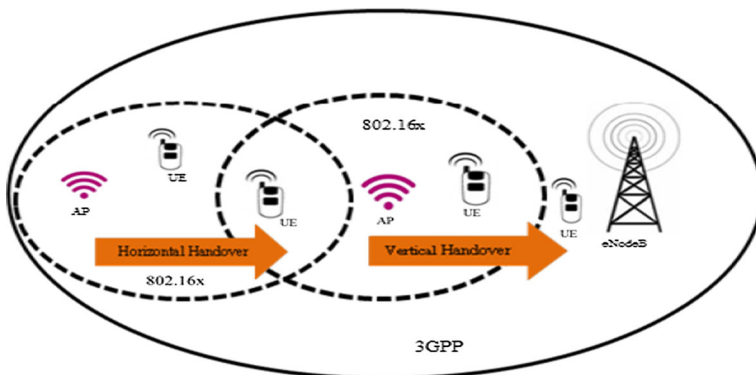
Fig. 1 Representation of vertical and horizontal handovers in WHN

2 Related Works

Most of the researches conducted on network selection tried to investigate the problems associated with seamless handover and access network selection was found to be very relevant to the initial network selection decision for users having multiple available choices. It is equally important to consider user experience and user preference when deciding which network to choose. Many of the radio access network (RAN) selection strategies do consider user requirements and preferences, but in the context of the network-centric vision. User preference information is often used to the operator advantage so as to maximise revenue and network utilisation. For Chan et al. [3], the behaviour of users was understood for maximising network gains and did not consider user-centric approach but rather considered congestion-based pricing to influence the user behaviour with the goal of optimal resource allocation. In some existing literatures, users take advantage of the competition among operators and connect to the always best connected network. Lee et al. [4] proposed a network selection technique that provides users with the serving best available network, while considering user preferences, bandwidth availability and the application requirements. This assertion has been corroborated by Ahmed et al. [5].

Cheng et al. [6] suggested a QoS based vertical handover decision scheme by considering available bandwidth and user preferences for deciding the handover direction from a WLAN to WWAN and inverse. When an UE is connected to a WLAN, the proposed scheme is initiated by checking the state of the terminal and by comparing the RSS level with a predefined threshold. If the mobile UE is found in the idle state then a handover is performed towards the preferred access network otherwise, application type is considered for making a handover decision. Similarly, if WWAN provides higher bandwidth as compared to WLAN then a handover is performed for delay-tolerant applications. The proposed methodology tends to have achieved higher throughput and lower handover latency due to the utilization of available bandwidth and application type as main handover decision criteria, respectively.

Bazzi [7] proposes a new definition of the softer VHO in contrast to the existing one [8] along with an algorithm for heterogeneous wireless systems to support the discussion. This definition takes into consideration the network conditions like user mobility, available bandwidth and application type. The proposed definition mainly focuses on the best effort service in the UMTS networks using different mobility scenarios. An analytical model is also proposed that works for multimode terminals and uses some dynamic lists that measure the perceived throughput of the connected terminals for the best network selection. The proposed algorithm improves the overall throughput for a softer handover however, other aspects of the QoS like handover delay and packet loss, seems to be totally ignored in all scenarios.

Lee et al. [8] propose integration of WLAN and cellular networks for connection and optimal resource management by considering coverage area, available bandwidth and RSS for achieving seamless handover. In the proposed mechanism, handover to cellular network is performed only if no other data network is found in the vicinity. This is done due to the limited capacity of handling heavy traffic loads by cellular networks. This scheme achieves proper load balancing and optimized battery life of the mobile terminals by restricting the off and on switching thus, reducing the Ping-Pong effect and number of unnecessary handovers. The performance of SINR and RSS based vertical handover algorithms is assessed where the proposed SINR based scheme delivers improved system throughput and reasonably low handover dropping rates when compared to the existing RSS oriented

method. Major drawback of this approach is that it is dependent on the velocity of the mobile users and performance of the scheme degrades with the increase in velocity. Also, this scheme provides high latency and a very high number of unnecessary handovers.

In [9], authors propose a novel handover technique for reduction of handover failure probability and elimination of unnecessary handovers. In order to achieve these functions, they have fused together three different techniques: (1) signal trend detection indicate the need of upward or downward vertical handover. For example, if a mobile node is entering in WLAN coverage area and RSS is raising then the handover is triggered to the nearest WLAN access point. (2) adaptive threshold fixing is used as a trigger that adjusts to variations in MNs' velocity and channel parameters and it also estimates the possible handover delays and, (3) a dwell timer for fast moving terminals since at high velocities a mobile node (MN) must handover immediately as it enters or exits the coverage area of a specific network. This timer helps in fast handovers and reduces the waiting time. So, dwell timer interval is reduced for high speed MNs in the proposed mechanism. This scheme successfully reduces handover failure and ping-pong effect but some surplus amount of signalling is observed that eventually affects packet loss as well.

Li et al. [10] used a layer 3 prediction scheme to reduce the handover latency in a two-tier Femtocell networks. The scheme was integrated into the user equipment (UE) part of industry-preferable mobile-assisted network-controlled handover (MANCH). Some of the key features of this proposed prediction scheme is the ability to filter reference signal received power (RSRP) meant to activate L3 handover prior to Layer 2 (L2) handover procedure. It equally is capable of improving. Their model is based on the UEs' movement pattern designed by considering the characteristics of the UE's movement pattern.

Kim et al. [11] proposed a novel vertical handoff algorithm between WLAN and CDMA networks that is capable of integrating of these networks. Their proposed work handoff algorithm triggers the received signal strength (RSS) that assumes a handoff decision process (handoff triggering and network selection). Although the purpose is to reduce the likelihood of unnecessary false handoffs, the distance criterion is also considered.

In Stemm et al. [12] architecture of vertical handover is proposed for multi-homed terminals in a wireless overlay network. It is based on Mobile IP though with little modifications. In order for the mobile terminal to make the decision of the right network and base station (BS) to switch to, a handoff controller is incorporated to do that. However, the decision to select such a network is based on network availability. This implies that an increase or decrease in received beacons from the surrounding BSs might be influenced by network constraints outlined by the user on the terminal or by heuristic advice from a subnet manager.

Adamopoulou et al. [13] present a mobile terminal architecture where a guide user interface (GUI) is incorporated on the mobile node to collect and weight four parameters (quality, preferred network, technology type and cost) of the indicated user preference for every service request. Their terminal management architecture consists of a network interface adaptation module, a mobility management module and the user preference module. The network selection is performed by the intelligent access selection function in the mobility management module. The cost information is received from the networks in advance of network selection and is not expected to change frequently. Each network operator charges per data volume, or per unit time, for access at a specific quality level.

Song et al. [14] have their user-centric network selection module implemented in the link layer, with cross-layer signalling messages delivering the QoS information from different layers in the IP-stack, including the application layer where the user describes their desired attributes in a QoS Context. The scheme is based on a large number of

parameters which describe; availability, throughput, timeliness, reliability, security, and cost. Two mathematical techniques, analytic hierarchy process and grey relational analysis, are used to perform the analysis and trade-off between the parameters. The decision maker then chooses the network with the best score.

Wang and Binet [15] in their study on network selection found usefulness in adopting MADM-based as one of the popular models to select the right wireless. However, they identified some issues considered important that have not been well solved, such as the requirement of efficient weighting method, the usage of VHO properties, the trade-off for handing-over to the new best network, and the immoderate load balancing compromising importance of other criteria. They therefore proposed a four-step integrated strategy for MADM-based network selection consisting of SAW, TOPSIS, MEW and GRA.

Hussein et al. [3] proposed a fuzzy logic based framework for handover decision making and a classification of the available solutions. They mainly concentrated on the MADM based approaches. Bhosale et al. [16] mainly concentrate on the micro- and macro-mobility solutions along with the description of related protocols. This classification mostly concentrates on the handover related issues in general. After identifying handover decision as a fuzzy MADM problem, this sub-section deals with the selection of the decision method. In the context of handover decision, the potential handover candidates and criteria can be numerous and the decision may have to be made frequently. This requires the decision method to be scalable and easy to use. In addition, it has to be flexible, so that a user can change his preference on the criteria easily. It is possible to directly use the methods in the fuzzy for handover decision. But the methods in this group are either too cumbersome to use, or only suitable for the purpose of screening out unsuitable alternatives. The fuzzy MADM methods with data type is all fuzzy require transforming crisp data to fuzzy numbers, despite the data are crisp in nature, which not only violates the intention of fuzzy set theory, but also increases the decision complexity.

If the fuzzy data are linguistic terms, they can first be converted to fuzzy numbers using a conversion scale. Then the result fuzzy numbers are converted to crisp numbers. For instance, if five linguistic terms are used to represent the possible user preference: very low, low, medium, high and very high, these linguistic terms are first converted to fuzzy numbers using the conversion scale where both the performance score x and membership function μ (x) are in the range from 0 to 1 as demonstrated in Fig. 2. A fuzzy scoring method is used to convert each fuzzy number to a corresponding crisp value.
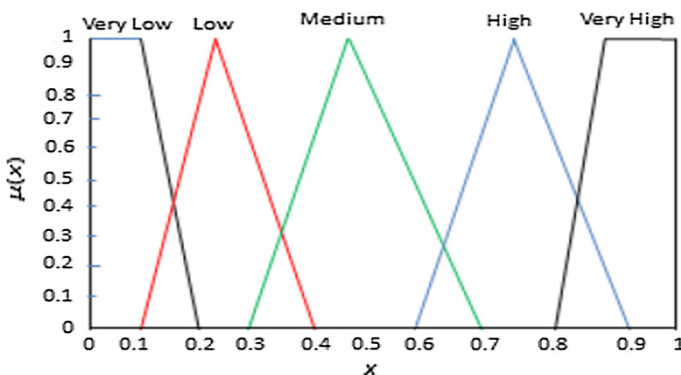
Fig. 2 Linguistic to fuzzy number conversion scale

Wang and Binet [15] did not specify which classical MADM method to use. From the dozen classical MADM methods, some MADM methods are either very lengthy or give biased ranking [17], which does not form subject of discussion here. Among the classical methods, simple additive weighting (SAW) method considered as one of the best known and widely used methods in this regard is adopted. The overall score of an alternative is computed as the weighted sum of all the attribute values.

As a summary, for handover decision, Wang and Binet's method will be used to convert imprecise linguistic terms to crisp numbers, and SAW will be applied for the final ranking. It should be noted that, different from previous approaches, the introduction of fuzzy logic in this paper is only used to deal with the inherently imprecise information. It is easy and flexible, allowing users to change the preference, or even the decision criteria for various applications in different environments.

After carefully analysing all the different methods of handover decisions for network selection, a generic network selection algorithm is developed that helps the handover decision making process by incorporating the QoS and other contextual information which is generated as a result of cooperation between the network entities. A fuzzy logic concept in this respect provides a robust mathematical framework where decision to select the best network is formulated as a fuzzy MADM.

The mix of these services has a great influence on system performance in terms of ability and availability. Therefore, the QoS analysis is generally assimilated by the discrimination of services by the definition of different class of service. These classes are defined to facilitate the negotiation process between the mobile equipment and the network. The major difference between these classes is the sensitivity of each service class to the latency, the delay variation and the packet loss ratio.

The goal of this step is to ignore the network that does not satisfy some required criteria by the mobile user. For example connection is required if the RSSI and bandwidth are higher than the threshold. The networks which did not meet these contextual criteria are then ignored. The objective is to choose the best solution that guarantees both perceived and provided QoS by end user. For this reason, the weight factor is introduced to select the point of attachment (PoA) providing the highest performance of the context criteria.

3 Membership Functions of Input Parameters for Vertical Handover Decision Algorithm

The decision to select an optimal access network is influenced by several factors which constitutes an aspect of service delivery in a heterogeneous wireless system. Network metrics are the qualities that are measured to give indication of whether or not a handover is needed. The following network parameters are particularly important for network selection and vertical handover decision.

3.1 Network Conditions (N)

Available bandwidth is mostly used as indicator of traffic performances in the access networks and transparent parameter for the current and future users of the multimedia services. This is the measure of per user bandwidth allotted by the network operator which is dynamically changeable according to network utilization. Transition to a network with better conditions and higher performance would usually provide improved QoS.

3.2 QoS Level (Q)

Delay, jitter, error ratio, loss ratio and other parameters can be measured in order to decide which network can provide a higher assurance of continuous connectivity. The levels of QoS should objectively be declared by the service provider based on ITU-T recommendation Y.1541 [25] and specified parameters. By declaring the QoS level in this way, complex examination of QoS parameters will avoided by users and the additional load of mobile terminals and other network elements.

3.3 Security Level (S)

When the information exchanged is confidential, a network with high encryption is preferred. The security level concept, sometimes called level of security (LoS), is similar to level of service in QoS management. LoS is important information within a security profile and is used to determine whether user data is allowed to be transferred by a particular network or not.

3.4 Pricing (P)

The cost of services can significantly vary from one provider to the other, but in different network environments. In some cases cost can be the deciding factor for optimal network selection, and it includes the traffic costs and the costs of roaming between heterogeneous networks. In some context, cost of service is in tight relation with network conditions, QoS level, security level, but in next generation wireless environment, cost of service is fast time differentiable function dependable of many others parameters. Pricing schemes adopted by different service providers is crucial and will impact the decisions of users in network selection.

3.5 Membership Function of Sensitivity (RSS)

RSS-based handover algorithms provide solution to optimizing vertical handover problems for cellular communications. When an RSS-based handover scheme is to determine when to initialize the handoff procedure was presented in [10], it creates Ping-Pong effects as the mobile user equipment (UE) roams between adjacent networks. This Ping-Pong effect causes unwanted handovers. Additionally, a neural network scheme was employed to determine when an RSS-based approach can perform the handover procedure [11, 17]. These approaches (RSS-based) however, failed to produce optimal results for vertical handover. A hysteresis using a margin between two thresholds was implemented by [11] to stop the ping-pong effect. A combination of RSS-based handover scheme and a hysteresis were considered to improve performance [5, 18]. In order to avoid handing over to a wrong base station [5], opted for using both the RSS and the distance between a radio base station (RBS) and mobile user equipment (UE). The problem remains same as RSS is a function of distance in heterogeneous wireless networks. A multi-level fuzzy theory is applied in order to solve the impending problems.

Let $S(x)$ stands for the sensitivity (received power level) of the candidate eNodeB, and define S_{th} as the threshold of the sensitivity. Assume S_{max} to be the maximum sensitivity detected by a candidate eNodeB. Applying the factor of normalization as S_{max} and $S(x)$, a

piecewise linear membership function of sensitivity S given in Eq. (1), with, x denoting the location of users.

$$\mu_1 = \begin{cases} 0, & 0 \leq S(x) \leq S_{th} \\ \dfrac{S(x) - S_{th}}{S_{max} - S_{th}}, & S(x) > S_{th} \end{cases} \tag{1}$$

3.6 Membership Function of BW

Bandwidth is a measure of the difference between the upper and lower frequencies in a contiguous set of frequencies. In order to provide seamless handover for quality of service (Qos) in wireless environment, there is a need to manage bandwidth requirement of the mobile node during mobility. It is known generally as the network link capacity. The higher the offered bandwidth, the lower the call dropping and call blocking probabilities, hence higher throughput [19, 20]. The quantity of unutilized bandwidth by the eNodeB is given as $BW(x)$, while BW_{max} is assumed to be the maximum value of bandwidth provided by the candidate eNodeB. The membership function of the BW is shown in Eq. (2).

$$\mu_2 = \begin{cases} \dfrac{BW(x)}{BW_{max}}, & 0 \leq BW(x) \leq BW_{max} \\ 0, & BW(x) > BW_{max} \end{cases} \tag{2}$$

3.7 Membership Function of Cost

Handover cost as defined by Savitha and Chandrasekar [21] is a function of available bandwidth and monetary cost. Mobile users were proposed a policy-enabled handover system [22] to decide the best wireless system at any point in time. As a result, a trade-off was made between network characteristics and dynamics (cost, performance, power, etc.) to avoid handover instability. These two proposals of [21, 22] are similar, in which RSS and bandwidth availability were chosen as the vital parameters for the cost function. The ping-pong effect still remains as the approaches addresses only the RSS threshold.

Similarly, $C(x)$ is defined as the network's initial cost of operations in which the candidate eNodeB resides and C_{th} is the threshold cost of the network. The expression, $C(x) \geq C_{th}$, could be considered as the expenses of network operating cost assumed to be costly by fulfilling the condition. Therefore, the membership function of C is expressed as Eq. (3).

$$\mu_3 = \begin{cases} 1 - \dfrac{C(x)}{C_{th}}, & 0 \leq C(x) \leq C_{th} \\ 0, & C(x) > C_{th} \end{cases} \tag{3}$$

Therefore, Eqs. (1–3) are the defined membership functions of the three metrics considered in this work, vis-a-viz: sensitivity (RSS), bandwidth (BW) and cost (C) of the candidate network. These will be the conditions to be used in determining or selecting the best target network from the available networks.

4 Degrees of Membership and Weight Vector of Target Base Stations

Fuzzy logic (FL) could be referred to as a method for problem-solving control system (multi-valued logic) that easily attain certain conclusion based on vague, ambiguous, imprecise, noisy, or missing input information. The FL approach to the control problem entails the way decisions are quickly taken [28]. It integrates an easy, rule-based approach (IF X AND Y THEN Z) to solve a control problem instead of modelling a mathematical system. The quantity and the complexity of the rules are determined by the quantity of the input parameters that need to be processed and the quantity of fuzzy variables that are linked to every parameter. The membership function, in which the triangle function is common, is a graphical representation of the magnitude of the participation of each input at the fuzzifier. It assigns a weight to each of the inputs that are processed and defines the functional overlap between the inputs. The fuzzy inference engine develops a decision according to the fuzzy rule-based table. The de-fuzzifier ultimately determines the output response as depicted in Fig. 3 which shows a typical FLC system configuration.

The establishment of membership functions make it possible and easy to compute the membership degrees of the input parameters for every candidate eNodeB. To evaluate either of the eNodeB, there is the need to establish weights for the input parameters to sustain the VHD value of each eNodeB. The eNodeB with the highest VHD value is chosen as the target network to be handed over to, only if it fulfils the conditions of the VHD Margin constrain after comparison.

4.1 Membership Degrees

Considering n candidates of eNodeBs: BS_1, BS_2,…, BS_n and employing the membership functions in Eqs. (1–3), the membership degrees of the three inputs (sensitivity, BW and C) are determined for each eNodeB and tabulated as Table 1.

The table shows membership degree μ, as the first subscript stands for the input parameter, while the other subscript represents the eNodeB.

The membership vector U_k of the kth ($1 \leq k \leq n$) base station BS_k could be written as in the Eq. (4).
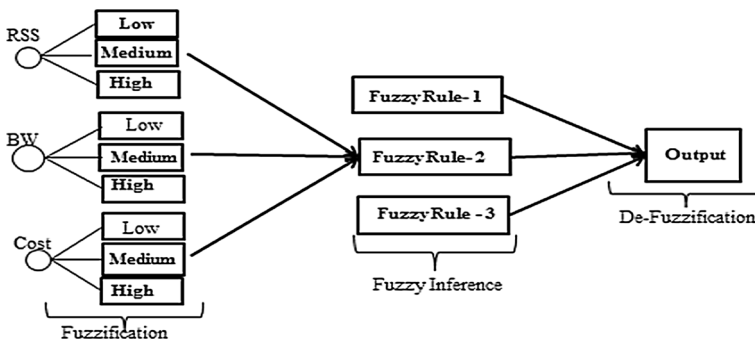

Fig. 3 Fuzzy logic systems

Table 1 Membership degrees and parameter values for the eNBs

	Sensitivity	Bandwidth	Cost	Opt. VHD
eNodeB_1	$\mu_{1,1}$	$\mu_{2,1}$	$\mu_{3,1}$	$F_1(x)$
eNodeB_2	$\mu_{1,2}$	$\mu_{2,2}$	$\mu_{3,2}$	$F_2(x)$
eNodeB_3	$\mu_{1,3}$	$\mu_{2,3}$	$\mu_{3,3}$	$F_3(x)$
:	:	:	:	:
:	:	:	:	:
eNodeB_n	$\mu_{1,n}$	$\mu_{2,n}$	$\mu_{3,n}$	$F_n(x)$

$$U_k = \begin{bmatrix} \mu_{1,k}(x) \\ \mu_{2,k}(x) \\ \mu_{3,k}(x) \end{bmatrix} \tag{4}$$

The weight vector W for the 3 membership are defined as

$$W = (w_1, w_2, w_3) \tag{5}$$

The new multi-level vertical handover (MLVHO) technique is therefore a combination of the Eqs. (4) and (5) to give the relationship $F_k(x) = Wu_k$, equally expressed as

$$F_k(x) = WU_k = w_1\mu_{1,k}(x) + w_2\mu_{2,k}(x) + w_3\mu_{3,k}(x) \tag{6}$$

Therefore, same method is employed to evaluate the entire n candidate BS_1, BS_2..., BS_n by relating the degree of membership matrix to the vectors of the n BSs as demonstrated by the equation:

$$U = (u, u_2, \ldots, u_n) \tag{7}$$

Finally, vector F is defined as a multiple level vertical handover decision and relates with $F(x)$—MLVHD value as formulated in Eq. (8).

$$F = (F_1(x) F_2(x), \ldots, F_n(x)) \tag{8}$$

Combining Eqs. (6), (7) and (8), the expression becomes

$$F = WU \tag{9}$$

4.2 Weight Vector

Considering the unpredictable environmental conditions, the values of power sensitivity, bandwidth and cost as well as their membership degrees keep on changing unpredictably. Consequently, achieving optimal vertical handover under these varying conditions become difficult and therefore the necessity to determine the Weight Vector W, which should come to term with the following: (1) must be dynamic to be able to respond appropriately to the unpredictable conditions, (2) It should be able to always reflect positively on the weights and relationships of the dynamically changing membership degrees and (3) increased dominance gap of specific membership degree(s) among the candidate eNodeBs by assuming such difference for BS_1, BS_2,..., BS_n to be the sensitivity, when BW and C might be either same or close. Then, the weight of $\mu_{1,k}(x)$ (for $k = 1, 2\ldots n$), w_1 should be the largest. This defines W (weight vector) according to [20, 23] to be:

$$w_i = \frac{\sigma_i}{\sum_{i=1}^{3} \sigma_i} \tag{10}$$

$$\text{and } \sigma_i = \sqrt{\frac{1}{(n-1)} \sum_{k=1}^{n} \left[\mu_{i,k}(x) - \frac{1}{n} \sum_{k=1}^{n} \mu_{i,k}(x) \right]^2} \tag{11}$$

is the standard deviation of $\mu_{i,1}(x)$, $\mu_{i,2}(x)$,…., $\mu_{i,n}(x)$ for $i = 1, 2, 3$Hence, the decision for selecting the target network with the highest NQV becomes the "best network" [24, 26, 27].

$$NQV_i = \sum_{i,j=1}^{N} W_j (P_{ij}) + \sum_{i,k=1}^{N} W_k \left(\frac{1}{P'_{ik}} \right) \tag{12}$$

NQV_i stands for the quality of the ith target network (TN), P_{ij} is the bandwidth and security, while P'_{ik} is the cost and energy consumption as benefit and negative-benefit parameters respectively. Consequently, W_j and W_k indicates the weights that represent how important the parameters P_{ij} and P'_{ik} are with N as the number of TNs.

5 The Proposed MLVHD Algorithm

In the MLVHD scheme, TN is considered when computing the handover rather than the mobile UE, as proposed in some literatures. The scheme considers: cost (monetary cost of installation and service charge) and bandwidth as the metrics to be used in the evaluation to heuristically select a suitable target network. These metrics are presented as fuzzy multiple characteristic decision making (MXDM) access selection function that employs the service of a simple additive weighting (SAW) method. The network selection function seen as a problem in decision making adopts a MADM, that evaluate sets of alternatives (networks) having varying benchmarks for the network selection function (NSF) that contain the parameters of signal strength, bandwidth and cost. The NSF provides a measure of the TN network quality value (NQV) as expressed earlier in Eq. (12) and depicted in the algorithm of Fig. 4.

5.1 The MLVHD Process

Making reference to Fig. 4, the multi-level VHD scheme has the following stages:

- The mobile UE initiates a handover process, before sending requests to evaluate the entire message to be detected in the neighbouring networks. The requested information is to contain the required parameters of the mobile UE and their respective weight values.
- The task of computation is executed on the TNs, with each TN applying the network selection function (NSF) on to the required parameters. MADM is however introduced to calculate the NQV, where the value obtained is sent to the UE, through the network evaluation response NQV message.
- At the end, the mobile UE selects the target network with the highest NQV and transfers all resources to the selected target network.
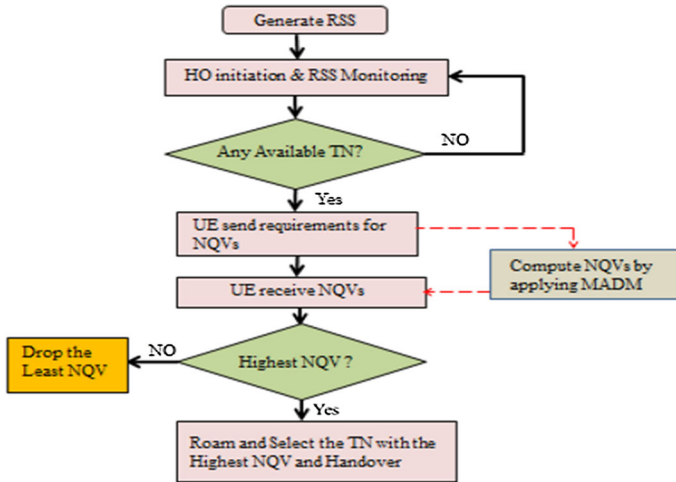
Fig. 4 Flow diagram of the MLVHD algorithm

5.2 The Multi-level Vertical Handover Scheme

A MLVHD is proposed to assist in enhancing the overall handover decision by exchanging messages, offered between the mobile node (UE) and the target networks (TNs). Assumptions were made in modeling the mobility environment, which include:

1. Mobile UE moving in an overlapped zone that covers variety of wireless networks operated by one service provider.
2. The entire mobility area is covered by the cellular network, while the WLAN has limited coverage, as illustrated in Fig. 5.
3. Two categories of networks are considered here: the cellular network which is the serving network (SN) while the WLANs are the target networks which are sometimes referred to as the visiting networks (VNs) where the UEs roam.
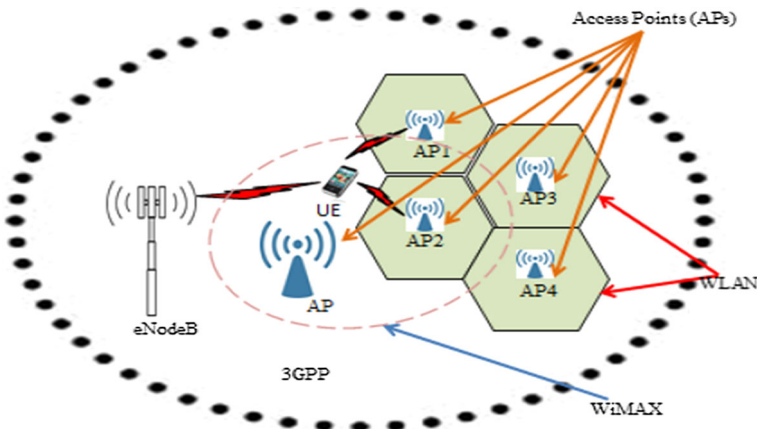

Fig. 5 Considered system model

4. Assumption: WLAN supports higher data rates, whereas the SN provides relatively low data rates. Also it is assumed that Ni represents the cellular system and Nj (j = 2, 3,…, N) refers to WLAN networks like WiMAX and Wi-Fi.
5. Mobile UE might be running data streaming application like voice over IP (VoIP) which does not accept poor QoS.
6. The assumption is for both the UE and networks to be network quality value (NQV).

Going by the mentioned procedure described earlier, the MLVHD vector F of the kth ($1 \leq k \leq n$) base station BS_k can then be determined once two conditions are satisfied:

$$F_k(x) = max\{F_1(x), F_2(x), \ldots, F_n(x)\}; \tag{13}$$

$$F_k(x) - F_j(x) \geq F_{th} \tag{14}$$

where $F_j(x) = max\{F_1(x), F_2(x), .., F_{k-1}(x), F_{k+1}(x), \ldots, Fn(x)\}$ and F_{th}—this is the threshold of MLVHD value that assist in eliminating the unnecessary vertical handovers with the target base station k BS chosen as the final one for the handover.

6 Simulation

6.1 Simulation Set up

In this simulation, consideration is given to the system model of Fig. 4, which consists of the following:

- An overlayed network with four networks.
- A Bandwidth unit of 5 is provided for the network N, while network N_i ($i = 2…N$), a bandwidth units ranging from (1…20) is being provided.
- VoIP applications are being operated by the mobile user and therefore require a very good and stable bandwidth.
- An assumption that the mobile UE is always connected to a minimum of two networks, N and N_i ($i = 2…N$).

In trying to evaluate the MLVHD scheme, parameters such as throughput, processing delay and blocking rate are given priority and the results from this is a comparison of the MLVHD and other types of VHD as described in most of the previous literatures.

6.2 Topology of Simulation Model

System model comprises of three overlapped networks of Wi-Fi, WiMAX and Cellular. Each of these networks' BS overlay one another shared by both BSs. The handover take place among the access points (APs) of Wi-Fi, WiMAX and BSs of Cellular network. The parameters of all the BSs and APs are shown in Table 1. The scheme operates by performing a pre-selection of foreseeable candidate networks by employing the sensitivity (RSS) of the network so as to curb the complexity of the fuzzy logic system (FLS). The FLS applied various sources as inputs including RSS of both the serving and target. Comparisons are of this scheme and those of other algorithms that are based on load thresholds and fixed coverage. Knowing fully well the robustness of wireless networks resulting in varying load conditions and coverage, simulation could be carried out by simply considering the movement of UE in straight path as it roams through a mix of

candidate base stations (BSs) and access points (APs). The route is assumed to be a straight line movement that cut across the coverage areas of these networks, as illustrated in Fig. 6.

6.3 Simulation Results and Analysis

The results of the proposed algorithm (MLVHD) using the fuzzy control theory to optimize the selection of the best network from variety of networks are presented here in Figs. 7, 8, 9. The evaluation of the proposed scheme is done by simulating two scenarios; the first scenario considers that the mobile UE is overlapped by two TNs, and in the second scenario the mobile terminal is overlapped by four TNs. The decision matrix is first normalized through linear normalization process expressed by Eq. (1). All the weighting matrixes are also normalized by dividing each entry by total of its columns; the normalized weights are shown in Table 1. The nominalized decision matrix derived from the Table is shown below in form of Table 2. At last we can obtain ranking by Eq. (2) using nominalized decision matrix (NDM) and nominalized weights according to application and user preferences from Table 2 as inputs. First NDM is calculated using linear normalization and multiplied with normalized weight e.g. voice. Using Eq. (9) first the minimum score of all alternative and then the maximum among them is selected for handover. The values of the parameters used in the simulation are given in the Table 3.

Plots for the bandwidth, cost and power level (RSS) for normalization are shown in Figs. 7, 8 and 9 respectively. The values of these factors vary with regard to the location of the mobile users. In Fig. 7, the difference between the bandwidth normalization of BS1 and BS2 is not much. It falls between 0.6 and 0.9 because both Wi-Fi and WiMAX interfaces have almost same high bandwidth. However, handover occur at distance 1600 m when BS2 increases while BS1 decreases until it degrades to 0.6 at 200 m from BS1. The choice of network depends on the user preference. In Fig. 8, the normalization shows the choice of BS1 over BS2 to always be high. At the distance of 300 m, services provided by BS2 are found to be expensive. This is about 3 times higher when compared with the cost at distance between 1200 and 2000 m. However, the plot of the RSS indicates a steady cost even when the signal strength of BS1 is getting weaker (Table 4).
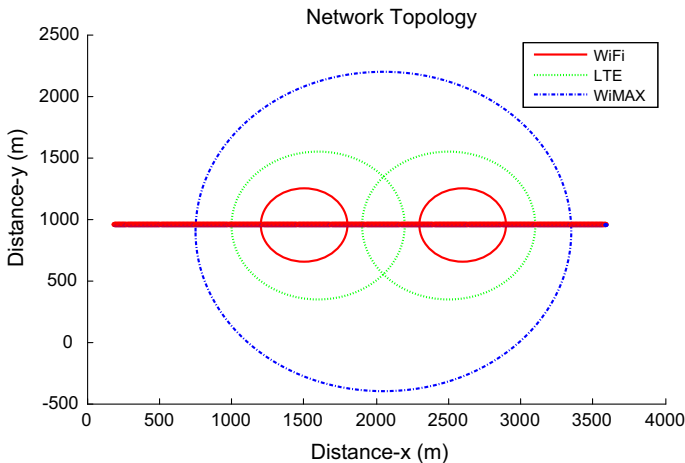
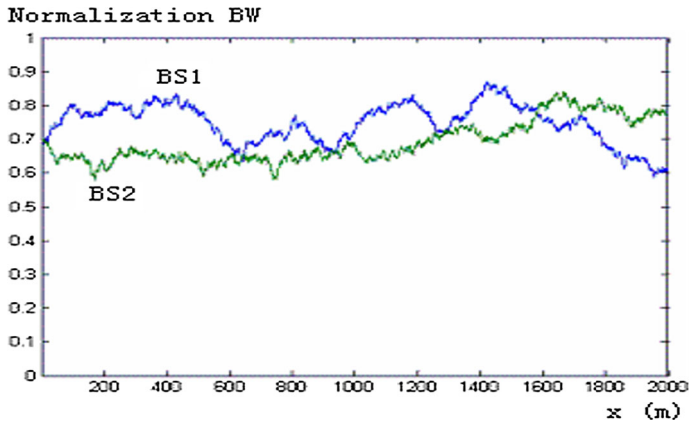**Fig. 6** Simulated topology of the scenario
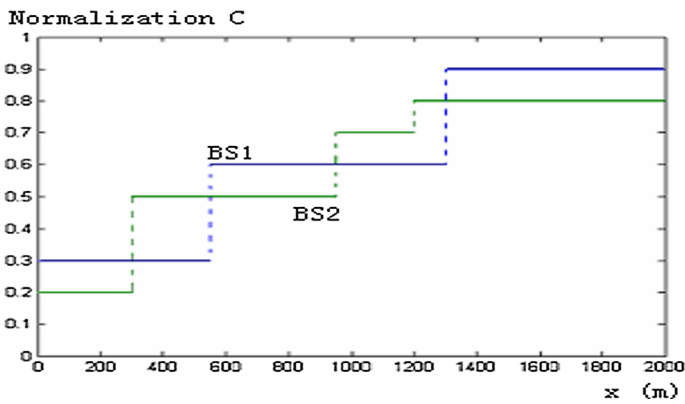
Fig. 7 Normalization bandwidths of BS1 and BS2
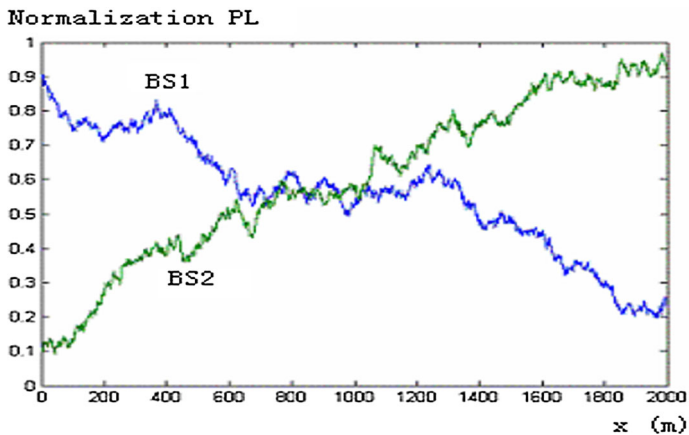

Fig. 8 Normalization costs of BS1 and BS2

Fig. 9 Normalization sensitivity (RSS) levels of BS1 and BS2

Table 2 Normalized weights

	BW	Cost	RSS
Voice	0.1840	0.1840	0.2639
FTP	0.2639	0.2639	0.1840
Browsing	0.1531	0.2704	0.1531
Streaming	0.1587	0.2275	0.1587

Table 3 Normalized decision matrix

	BW	Cost	RSS
BS1	0.875	0.2222	0.8889
BS2	0.75	0.2857	1
AP	0.875	0.6667	0.6667

Table 4 Simulation parameters

Parameter	Network type		
	Wi-Fi	WiMAX	LTE-A
BS parameter			
Operating frequency (MHz)	2450	2400	2600
Transmit power (dBm)	15	25	33
Cell radius (m)	300	600	300
MS parameter			
Receiver sensitivity (dBm)	−11.7	−100	−97
Cell edge receive level (dBm)	−110	−99.1	−98

Figure 9 describes the MLVHD Values of the base stations. As the mobile user moves further away from the first base station and approaching the second base station, the power level (signal strength) received by the UE start to deteriorate while that of the base station 2 builds up. At a certain point, the UE chooses the best station that has the strongest power (received signal strength) and decides to handover at a distance 800 m. The value of the signal strength however determines the decision for the vertical handover.
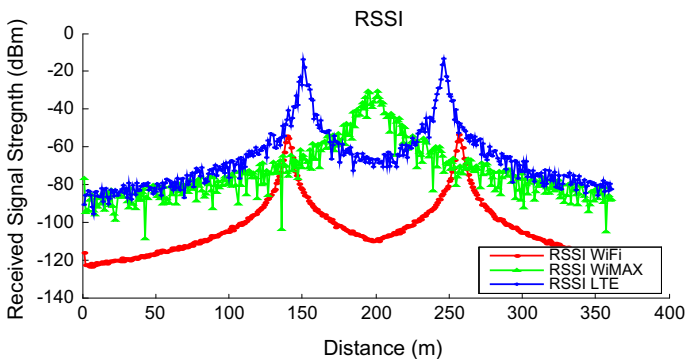
Fig. 10 Horizontal and vertical handover

Figure 10 indicates the locations where vertical handover decisions occurred. The figure describes the vertical handover decision with regard to the location x. It is shown that the FVHD Values of the candidate BSs serve as a reflection of the integrated evaluation of PL, C and BW in which the vertical handover decision is based on the FVHD Values.

The trajectory of the UE in the heterogeneous wireless network shows the changing curves of the RSSI from the candidate networks along the chosen path, which are varying with the changing of UE location as could be seen in Fig. 6. At the beginning of the simulation, the UE was served from the base station BS_1 of the LTE-A network since it is considered the preferred network with high RSSI and sufficient bandwidth. At about 90 s of the UE movement, the RSS of the preferred network reaches its peak and slowly decreases and handed over to the WiMAX network having strong RSS enough to provide the required resources to the UE at 100 s.

The dramatic decrease in bandwidth occurred at a period 225 s when the second base station (BS_2) of the LTEA network once again takes over. The decrease consequently reduces the access point candidacy value of the WiMAX. The two (LTE-A and WiMAX) networks provides appropriate bandwidth for the services rendered. However, the candidacy of Wi-Fi remains unnoticed as a result of weak RSS and possible bandwidth cost. For every simulation time point of attachment (PoA) is calculated, as the mobile UE has access to all the three networks at any point in time. The PoA are determined by choosing the highest value of the RSSI as depicted in Fig. 10. The target network at every handover location is seen to happen at different time as shown in Fig. 10.

The proposed approach decides handover three times only and reduces the handover decision time drastically by several milliseconds.

6.4 Performance

Results of the simulations conducted to highlight the benefits of the proposed MLVHA technique are presented. They demonstrate the process of finding a trade-off between user's preferences, service requirements and networks performances. A software application is developed for testing the algorithm with three access networks environment. The mobile terminals follow Poisson distribution with an average velocity between 0 and 30 m/s using random walk model and the movements considered as stochastic process.

The first scenario shows that the user did not specify preferences for any of the parameters and so the weight ($W_1 = 0.44$) is determined for the weight coefficient of parameter N purely based on service demands (entropy). Besides, the safety parameter ($W_3 = 0.30$) has also proved to be important for this application while the Q and P are of less importance in this case ($W_2 = 0.10$ and $W_4 = 0.15$). The eNB1 is then considered as an optimal network because it is much better than any of the two networks according to all its parameters, except cost of service (Table 5).

The second scenario has the user's preferred parameter as network conditions having the parameter of weight coefficient $W_1 = 0.44$ determined through the entropy method in combination with user's preferences. Accordingly, the result indicates (Table 6) that eNB3 is chosen as the optimal network, although eNB2 is better when compared with other parameters. However, the difference between the parameter values Q, S, and P has proved to be marginal as compare to the significance of parameter NC.

For a lower cost of service required by user as shown in the last scenario, the parametric weight coefficient $W_4 = 0.56$ is set to combine with service requirements. It could be deduced from the results that eNB2 has the lowest cost of service (Table 7). Consequently, eNB1 is adjudged to be the optimal network because it provides higher level of QoS and

Table 5 Scenario 1

Parameter	NC	Q	S	P
Normalized				
eNB1	0.863	0.312	0.416	0.42
eNB2	0.866	0.161	0.79	0.774
eNB3	0.628	0.19	0.56	0.232
Wj	*0.44*	*0.10*	*0.30*	*0.15*
Weighted				
eNB1	**0.39**	**0.033**	**0.124**	0.070
eNB2	0.376	0.016	0.022	**0.121**
eNB3	0.278	0.019	0.019	0.35

NC Means Network Conditions (Bandwidth availability)

Q Stands for Quality of Service

S Stands for Security Level (Confidentiality)

P means Pricing (Cost of service provisioning)

Table 6 Scenario 2

Parameter	NC	Q	S	P
Normalized				
eNB1	0.494	0.288	0.389	0.088
eNB2	0.088	0.828	0.94	0.693
eNB3	0.876	0.456	0.824	0.614
Wj	*0.44*	*0.12*	*0.27*	*0.18*
Weighted				
eNB1	0.216	0.033	0.104	0.017
eNB2	0.041	**0.096**	**0.257**	**0.121**
eNB3	**0.382**	0.055	0.222	0.105

NC Means Network Conditions (Bandwidth availability)

Q Stands for Quality of Service

S Stands for Security Level (Confidentiality)

*P* means Pricing (Cost of service provisioning)

Table 7 Scenario 3

Parameter	NC	Q	S	P
Normalized				
eNB1	0.167	0.288	0.389	0.088
eNB2	0.252	0.828	0.94	0.693
eNB3	0.057	0.456	0.824	0.614
Wj	*0.12*	*0.17*	*0.17*	*0.56*
Weighted				
eNB1	0.021	**0.132**	0.104	0.567
eNB2	**0.032**	0.023	0.041	**0.577**
eNB3	0.009	0.035	**0.132**	0.159

NC Means Network Conditions (Bandwidth availability)

Q Stands for Quality of Service

S Stands for Security Level (Confidentiality)

P means Pricing (Cost of service provisioning)

security. In addition, the interface eNB2 also offers a greater network conditions ($NC_2 > NC_1$), but the parameter is less important.

In order to perform some efficiency evaluation, the proposed technique is then compared with RSS [19], cost function [20] and MADM [7] based techniques. The average blocking probabilities of RSS, cost function, MADM and the proposed technique when velocity of mobile terminals varies are presented in Fig. 11. The simulation results show that MLVHA based techniques (MADM) provide lower handover blocking probabilities
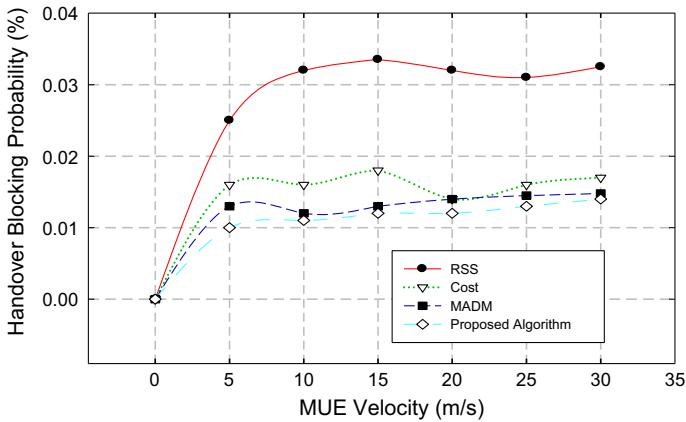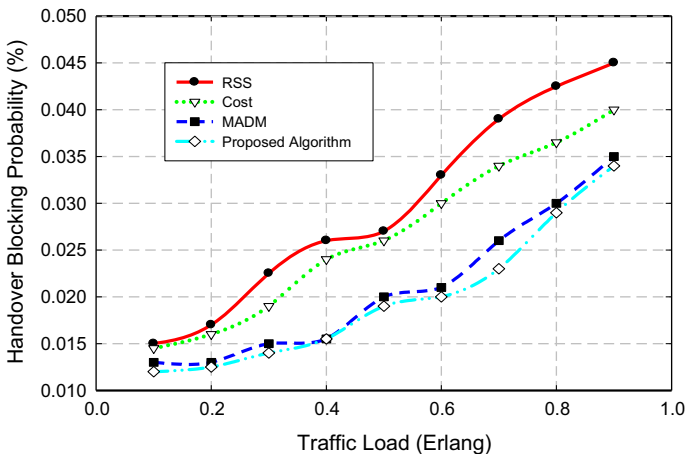
Fig. 11 Handover blocking probability versus MUE velocity

than that of the RSS and cost function based techniques. It also shows that blocking probability has no obvious relationship with the mobile terminal velocity.

The average handover blocking probabilities of observed techniques under different traffic conditions are shown in Fig. 12. Because the MADM based technique consider more normalized network parameters than the RSS and cost function based heuristics, the simulation results show that MADM techniques provide much lower blocking probability.

Furthermore, the blocking probability of the proposed technique provides about 4 % improvement to the MADM method. The results also show that the blocking probability is directly proportional to the traffic load. The blocking probability of all schemes increases as the traffic grows.

Fig. 12 Handover blocking probability versus traffic load

7 Conclusion

The need to perform handover in heterogeneous wireless networks is related to the QoS provided by the network and the QoS perceived by the end user. Therefore, in heterogeneous wireless networks, a big variety of factors based on criteria related to network performances, user preferences and service requirements can affect the decision to select the best access networks. This paper evaluates the performance of a proposed multi-layer algorithm for vertical handover decision. Network conditions, QoS level, security level and cost of service were integrated as trigger parameters. Through simulation studies, multi criteria analysis is envisaged as promising tool especially when MADM method is used. Results show that the proposed algorithm is simple and finds equilibrium between the user preferences, service requirements and networks.

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