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Fuzzy based multi-criteria vertical handover decision modeling in heterogeneous wireless networks

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Abstract Vertical handover gain significant importance due to the enhancements in mobility models by the Fourth Generation (4G) technologies. However, these enhancements are limited to specific scenarios and hence do not provide support for generic mobility. Similarly, various schemes are proposed based on these mobility models but most of them are suffered from the high packet loss, frequent handovers, too early and late handovers, inappropriate network selection, etc. To address these challenges, a generic vertical handover management scheme for heterogeneous wireless networks is proposed in this article. The proposed scheme works in three phases. In the first phase, a handover triggering approach is designed to identify the appropriate place for initiating handover based on the estimated coverage area of a WLAN

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access point or cellular base station. In the second phase, fuzzy rule based system is designed to eliminate the inappropriate networks before deciding an optimal network for handover. In the third phase, a network selection scheme is developed based on the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) decision mechanism. Various parameters such as delay, jitter, Bit Error Rate (BER), packet loss, communication cost, response time, and network load are considered for selecting an optimal network. The proposed scheme is tested in a mobility scenario with different speeds of a mobile node ranging from very low to very high. The simulation results are compared with the existing decision models used for network selection and handover triggering approaches. The proposed scheme outperforms these schemes in terms of energy consumption, handover delay and time, packet loss, good put, etc.

Keywords 4G · Heterogeneous wireless networks · TOPSIS · WLAN

1 Introduction

Next generation network mobility models emphasized on the integration of different wireless technologies such as WLAN, WMAN, Bluetooth, 3G, etc. The advantage of integrating these technologies for generic and seamless connectivity helps in reducing unnecessary traffic generation, frequent switching of a Mobile Node (MN) between these different networks, and security requirements. The interconnectivity can also help in prolonging the continuous connection between these networks. In general, there are two different type of wireless networks on the basis of its coverage area. One providing with short coverage area such as WIFI network and another providing high coverage area such a cellular and WiMAX networks. Both of these technologies have several advantages and disadvantages, for example, a WIFI is a low-cost technology which can be easily deployed in markets, shopping malls, schools, offices, and living apartments. On the other hand, cellular technology provides continuous connectivity in fast moving vehicles and trains. Similarly, WIFI technologies required daily or monthly maintenance, as well as its low coverage area, produces frequent handovers. On the other hand, cellular networks provide costly communication and thus can't be used for high streaming multimedia applications. The interconnectivity of different networks diverts the focus of researchers to new emerging concepts such as Cyber-Physical Systems (CPS), Machine to Machine (M2M) networking, and Internet of Things (IoT) communications. An example of such networks can be considered when a user forget his home appliance in on state instead of switching it off. The user remember but now its difficult for the user to go back home and switch off the device. If the user and appliance both are connected to a different network then with the help of interconnectivity between both the networks the user can easily control the appliance. Similarly, there are several examples exists of providing interconnectivity between heterogeneous wireless networks [13, 25]. But, still providing soft, ubiquitous, and seamless connectivity in these networks is a challenging job.

The mobility management is a vast field and it is studied extensively in the last decade. It is further divided into two main branches 1) handover and 2) location management. A handover process transfers an ongoing session from one Access Point (AP) or Base Station (BS) to another AP or BS with less possible delay and packet loss. An efficient handover management scheme can be designed by setting a wide range of parameters includes speed of the MN, bandwidth, data rate, RSS, etc. [18, 21]. Moreover, a handover process is initiated by the MN when its current connectivity drops below a predefined level of a parameter used for handover triggering such as RSS, SINR, bandwidth, etc. [5, 30]. The handover management is further divided into soft and hard handover. In the case of hard handover, the MN first breaks its current connection with the current AP or BS and establishes a new connection with a new AP or BS. Unlike hard handover, in soft handover, the MN first make a new connection with the target AP or BS and then breaks its connection with the current AP or BS. The traffic intends for the MN during handover is redirected through the new AP or BS and the resources of the old network is released after handover completion. Since, the time between starting a handover and completing it, is too short, therefore, the MN does not experience any disruption or connection connectivity during handover. A soft handover is further divided into three parts 1) horizontal, 2) vertical, and 3) diagonal. In the case of horizontal handover, the MN switches from one AP or BS to another AP or BS of the same network. In the case of vertical handover, the MN switches to another AP or BS of a different network while the route to the destination remains unchanged. Similarly, in diagonal handover the route and interface both are changed during handover. The vertical handover is an ideal choice of handover management for heterogeneous wireless networks. Therefore, the researchers are working hard to integrate the services of vertical handover management in IoT, CPS, and M2M communications. The vertical handover is further divided into three main parts i.e. handover initiation/triggering, network selection, and handover execution. The network selection can be performed by many ways and in the current literature various schemes are presented to select a target network [32, 44]. The Multi-Attribute Decision Modeling (MADM) is widely used for ranking and deciding an optimal network among the available networks [1, 42]. These decision models are briefly explained in the next section. However, the working mechanism of most of these models is similar. But, the time required to select a network during a handover process is very short, therefore, performing complex computation leads to high handover delay and packet loss. A hierarchy of the types of handover management is shown in Fig. 1.

Enabling generic connectivity among different internet providing technologies is a challenging job. A progressive step has been taken by IEEE in Nov 2008 by publishing a new standard called IEEE 802.21: Media Independent Handover Standard (MIH) [15]. The standard provides seamless connectivity between all the IEEE families and cellular networks. Recently, the standard is tested on test beds to analyze its performance in real-world scenarios [29]. MIH standard establishes a connection between lower and upper layers by deploying a new logical layer. Moreover, the communication of handover management is done by different events and services. The MIH uses three type of services which includes Media Independent Event service (MIES), Media Independent Command Service (MICS), and Media Independent Information Service (MIIS). It also uses Service Access Points (SAP) for the exchange of messages and functional planes of one technology with another [11].

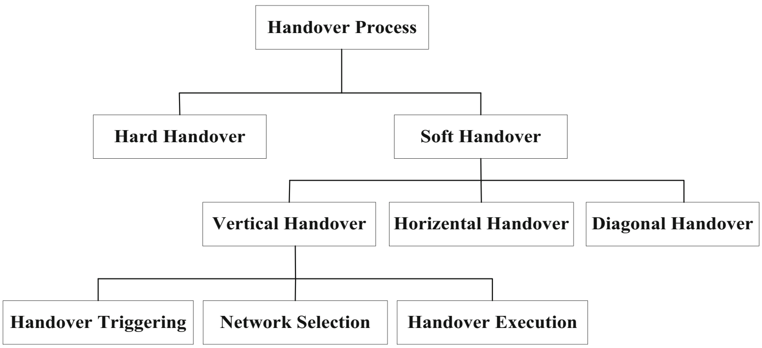


Fig. 1 Handover hierarchy

The MIH standard has still many issues and challenges which need to be addressed before deploying it for generic handover management. One of the main challenges in this regard is triggering a handover on the basis of RSS [19]. However, using RSS for handover initiation give birth to three different problems during a handover process. These problems are shown in Fig. 2. A dynamic handover management scheme is needed for future mobility models. Because, of the increasing number of wireless networks, the topology change highly affect a handover process. For example, if the MN is moving with a high speed in a smaller coverage area such as of WIFI's AP then there are a high chance of frequent handovers. Therefore, a handover scheme is needed which can incorporate the speed of the MN during a handover process. Similarly, there are other factors affecting the handover process presented in various literature needs refinement and enhancement [18, 36]. Due to these problems and challenges high handover delay and packet loss is introduced during a handover process, which ultimately leads to the breaking of MN's connection with the current AP or BS [37]. Therefore, in this article, we proposed a vertical handover scheme based on the decision modeling to enhance the working of existing schemes and make it more reliable and efficient for the future generation of networks. The proposed scheme incorporate various parameters during the handover process to select a target network among the available networks. The handover triggering mechanism is designed based on the AP or BS coverage area. Similarly, it helps the MN to trigger a handover at the appropriate place. Thus, it highly reduces the chances of problems shown in Fig. 2. The proposed scheme is tested in a number of different mobility scenarios ranging from a very high to a very low speed of the MN. The performance of the proposed vertical handover scheme is comprised in terms of handover latency, energy consumption of the MN, etc.

The rest of the paper is categorized as follows. Section 2 presents the a detail overview of the handover decision modeling and the schemes based on it. Section 3 describes the working of proposed scheme in terms of handover triggering and network selection. Section 4, illustrates simulation and results and finally the conclusion is given in Section 5.

2 Vertical handover decision modeling

2.1 Handover triggering

As stated above, the vertical handover is further consists of three main parts i.e. handover triggering/ initiation, network selection, and handover execution. A handover triggering referring to a

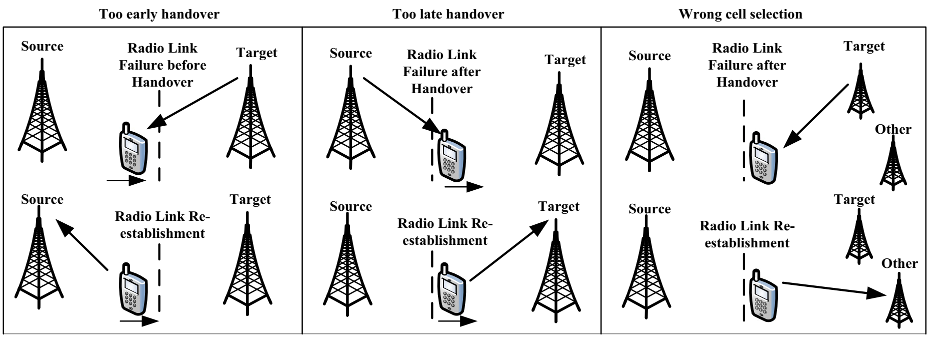


Fig. 2 Too early, too late, and wrong cell handover

phenomenon of initiating handover at the appropriate location. There are various parameters used to trigger a handover. The MN periodically checking the value of these parameters and comparing it with a predefined threshold. If the value of the parameter drops below a pre-defined threshold then the MN initiates the handover process. Various traditional handover approaches are based on the RSS value of the current network. The MN periodically checking the RSS level of the current AP/BS. If it is dropped below a certain predefined threshold, the MN initiates the handover. However, calculating and finding the exact location of triggering a handover process is a challenging task. Because, the time between the handover triggering and execution is very short [33]. A scheme based on finding the appropriate level of the RSS for handover triggering is proposed in [30]. The proposed scheme computes the RSS at the boundary of the coverage area of an AP/BS. Then it computes the minimum level of the RSS to hold a connection with the current AP/BS. The difference between both the RSS levels is computed and an adaptive threshold is defined on this RSS level. The computation of the adaptive RSS threshold (*Th[dB]*) is shown in Eq. 1.

$$Th[dB] = RSS_{border} - K_2 \log\left(1 - \frac{v}{R}(\Delta T)\right) \tag{1}$$

Where K_2, v, R, and ΔT represents the path loss factor, velocity of the MN, and handover delay, respectively.

The proposed approach efficiently solved the too late and early handover problems by using the proposed adaptive RSS threshold for handover triggering. Furthermore, the author stated that if the MN is moving with high speed and a fixed RSS threshold is used for handover initiation then the MN will experience significant packet loss. However, the wrong cell selection problem is not addressed. Similarly, the incorporation of the velocity factor with the proposed adaptive RSS threshold calculation increases the complexity of the system. Due to these problems the proposed scheme suffered from high packet loss if it take a longer time to compute the threshold value. Therefore, a scheme is required to perform handover triggering with less possible computation during the handover process. The literature consists of several other schemes which are directly based on a predefined threshold of RSS [8, 34]. For example, in [8], the authors estimated the predictive RSS of the neighbor BSs. The MN checks the RSS level of the current BS, if it is less than a predefined threshold, the MN compares the predictive RSS with the predictive RSS threshold. The handover is triggered if the predictive RSS is high than the threshold. Moreover, the proposed approach helps in obtaining the direction of the target AP/BS. A user-centric vertical handover always requires high handover time and energy, if the MN is moving with high speed. Thus, performing complex operations during the handover process required high energy. However, in the proposed approach the author did not provide the energy consumption of the MN during the handover process. The energy of the MN mainly consumes on scanning the available networks during a handover process. If the MN scans the available network after each s second using j joule of energy. Then performing n number of handovers in t time would require $(n \times t) \times j$ amount of energy. Therefore, it is important to consider the AP or BS arrival rate while designing a handover triggering scheme.

2.2 Network selection

The decision and selection process in heterogeneous wireless networks is a challenging job, because of the different characteristics provided by the different networks. Traditionally, researcher presents different handover techniques based on a single parameter. But, with the passage of time, the demand of the users have been changed dramatically. Therefore, the need of the MADM based network selection in heterogeneous wireless networks environment becomes very popular and its use is highly increased in recent past [10]. Recently, researchers proposed different parameter for selecting a target network and performing handover to it. These parameters include RSS, SINR, bandwidth, and etc. To efficiently utilize these parameters, researchers have proposed different decision functions. These functions are further divided into three parts: 1) utility based, 2) cost based, and 3) network scoring and ranking based.

A utility based handover decision function has been proposed in [31]. The proposed scheme uses a user-centric approach for vertical handover management. The network selection and interface switching have been performed by a terminal-controlled mechanism. They also use an aggregate utility mechanism to select an optimal network among the available networks. The utility decision function is given in Eq. 2.

$$U(x_i) = \prod_{m=1}^{M} [u_m(x_m)]^{am} \tag{2}$$

Where M represents the number of parameters used for the selection of a network, u_m is the decision function which takes a value of x_m, and αm is the weight of a network's parameter m. Similarly, the proposed approach uses a power saving management scheme to significantly minimized the energy requirement of the MN during a handover process. The use of RSS produced different problems as shown in Fig. 2. Therefore, employing this scheme for decision modeling in heterogeneous networks can generate high packet loss and failed handovers. A similar scheme has been proposed in [12]. The proposed approach exploits the user configuration to efficiently distribute the resources among different users in a heterogeneous wireless environment. A handover decision is performed by checking the values of allocated resources after a specific interval of time. These utility based functions do not guarantee an appropriate network selection because they do not offer independence among network selection parameter. The cost based function are widely used to select a target network during a handover process. Several schemes based on cost-based function has been proposed in the literature [9, 22]. These schemes perform the network selection on the basis of the applications running over the MN's device. For example, they rank the available networks according to the application priority. Most of the schemes calculate the cost of the available networks by summing up the values of the QoS parameters such as bandwidth, battery consumption, etc. However, most of these schemes are suffered from the QoS dynamics, weight assignment to the applications, etc. [28].

The MADM is a process of organizing different attribute for selecting a network among different networks. The MADM works by selecting different user attributes (UA = UA_i, i = 1, 2, 3… n) and comparing it with the network attributes (NA = NA_j, j = 1, 2, 3… m). The weights (W = w_1, w_2,…w_m) are assigned to user attribute in order to present the significance of these attributes. The user always selects the network which provides the highest value of all the attributes used for network selection. A scheme based on MADM approach called Enhanced-Simple Additive Weighting (E-SAW) has been proposed in [26]. The proposed scheme works in two parts. In the first part, the author proposed the elimination of those networks which do not satisfy minimum user requirements. A threshold-based mechanism is adapted for restricted the network selection to a specific number of networks. In the second part, the MN send its preferred parameters to the ranked networks. These ranked networks send its network selection function to the MN. The MN then decides handover to the network with highest network scoring function. The proposed scheme has still many challenges which need to be addressed for example the tradeoff between different parameter is not clearly defined. Thus implanting the proposed model in existing networks can produce high overhead and inappropriate network selection. A similar scheme based on the Weighted Product Method (WPM) has been proposed in [38]. The proposed approach is somewhat similar to the scheme presented in [26] except the weight assignment part. They assigned the weights based on the quality of the context. The proposed approach efficiently solved the dynamic decision-making problem in fast user movement. However, a user-centric scheme is not an efficient solution to the problem exists in the current handover schemes. Therefore, a scheme is needed which balance the user requirements with the full use of the network resources.

With the passage of time different decision modeling techniques have been proposed [24, 27, 43]. These techniques contain the well known and famous decision modeling such as TOPSIS [16], Grey relational analysis (GRA) [20], multicriteria optimization and compromise solution (VIKOR) [3], and ELimination and Choice Expressing REality (ELECTRE) [4]. In the case of TOPSIS, a network is selected on the basis of an ideal situation. If the rank of a network is closer to the ideal situation from other networks then that network is selected as the best network during the network selection process. Similarly, in the case of ELECTRE, the best networks are ranked using outrank relations employing pairwise comparison of alternatives and analyzing each parameter separately. The GRA decision model divides the situation into different categories i.e. black and white. The situation near to the white is more perfect than the situation near to the black. Therefore, in the case of network selection, the MN always select the network which is closer to the white situation. The white situation can be avail by comparing the parameters with a reference sequence (user-defined sequence). The MN define the reference sequence from the chosen parameters before starting the movement. During the handover process, the MN always compare the Grey Relational Coefficient (GRC) of the available networks with the GRC value of the reference sequence. Thus, the network has more closer GRC with the reference sequence is considered for network selection. The GRC calculation is shown in Eq. 3.

$$GRC_i = \frac{1}{N}\sum_{i=1}^{N}\frac{\varDelta_{min}+\varDelta_{max}}{\varDelta_i+\varDelta_{max}} \tag{3}$$

Where N is the total number of parameters and $\varDelta_{min}$ and $\varDelta_{max}$ represent the minimum and maximum value of a parameter i in a sequence.

There are different methods available in the literature based on the combination of more than one decision model. A hybrid scheme has been proposed by combining the MADM and SAW decision models in [39, 40]. The proposed schemes deployed MADM with the functionality of implanting a score function. The score function ranks the available networks on the basis of different parameters such as network conditions, monetary cost, power consumption, etc. Finally, the QoS of all the available networks is calculated as shown in Eq. 4.

$$Q_i = (W_{BW}\times BW_i) + \left(W_{DP}\times\frac{1}{DP_i} + W_{MC}\times\frac{1}{MC_i}\right) \tag{4}$$

Where, Q represent the quality of a network i, BW, DP, and MC, represent the bandwidth, dropping probability, and monetary cost, respectively. In order to enable user preferred values, the parameters are assigned with the weights W. Moreover, the author proposed, if all the calculation of QoS is done by the network itself, then the handover time will be highly minimized.

Recently, researchers combine the MADM decision models with various intelligent and fuzzy methods to make it faster for solving complex problems during a handover process. One of the models has been proposed to combine the ELECTRE decision model with a fuzzy system [3]. The author uses different parameters such as resource availability, MN's velocity, security level, and etc.

The working of proposed scheme is divided into two phases. In the first phase, the fuzzy system is applied for initial ranking of the available networks. In the second phase, the ELECTRE method is applied to perform final ranking and selection of an optimal network for handover. The proposed scheme efficiently reduces the handover rate and ping-pong effect present in the traditional handover methods. Although, combining a decision model with the artificial or fuzzy method is used to reduce complexity but the author did not provide any details of reducing the complexity of the system. They also do not discuss the complexity produce due to the parameters used in the handover process. In another work, a scheme based on VIKOR decision model has been proposed in [2]. The proposed scheme ranks the available networks and then selects one with highest resources. The proposed scheme uniformly distributed the resources with all the users after performing the handover. But, the scheme fails in providing the maintenance and handling functionalities for dissimilar information coming from different sources in the heterogeneous environment. In the above literature review, we discussed the famous decision models used for the selection of a network. The working of these decision models can be made more accurate by providing an efficient handover triggering technique. If a handover process is triggered at appropriate place and time, then it can help in reducing handover time and delay and a user can get full benefits of the resources offered by a network.

3 Proposed scheme

3.1 Overview

With the advancement of smartphones and their applications demands high data rate and ubiquitous communication services. Providing the uninterrupted services require high data rate and seamless connectivity in heterogeneous wireless networks. Each application requires a particular data rate to run smoothly over the internet. Moreover, a set of specific rules is defined by the ITU to choose a network during the handover process. These rules are based on the speed of the MN in the heterogeneous wireless networks. For example, if the speed of the MN is high then a cellular or WiMAX network is more favorable than the other networks. Because, the coverage area of the cellular BS is higher than the WIFI AP.

The proposed handover triggering technique computes the expected coverage area of an AP or BS. Similarly, the MN computes the expected time to cover the coverage area. A threshold is defined when the MN covers a particular distance in the coverage area of an AP or BS. The MN initiates the handover when the remaining coverage area drops below than the predefined threshold. Similarly, the target network is selected on the basis of various parameters such as delay, jitter etc. These parameters are obtained from the available networks and passed to the TOPSIS decision model. The TOPSIS decision model categorized these parameters to obtain the ranks of the available networks. The network providing the highest rank is selected for the handover.

3.2 Preliminaries

This section presents some of the important preliminaries in order to understand better the working of the proposed architecture in a heterogeneous wireless network environment. These assumptions are flexible and can be changed according to the network situation. Moreover, some of the important definitions are also given in the following sections. However, we followed these preliminaries during the design and implementation of the proposed scheme.

3.2.1 Assumptions and definitions

Assumption 1 (heterogeneous devices) Every device participated in the heterogeneous networks have a different configuration (if the technology is different). For example, the computational capabilities, mobility pattern of the device, battery requirements, network interface management, etc.

Assumption 2 (communication radius model) The communication model and coverage range of a device K (Access Point or Base Station) having radius R and centered at c, apart 100 m (AP) and 500 m (BS) from another device. It can be further defined as $C(c, R) = \{K_1, K_2 \in N : |D(K_1 - K_2) \leq R_{K_1}\}$, where C represents the coverage distance, N represents the deployed APs or BSs, and $D(K_1 - K_2)$ represents the distance between two access points or base stations in a heterogeneous network environment.

Definition 1 (medium scale network (MSN)) In the case, if we are considering a wireless network environment in a closed region and we want to analyzes the handovers performed by different MNs. In such an environment, if all the nodes are performing frequent handovers then the network is considered as Medium Scale Network (MSN). Suppose, in a closed region, 100 nodes are deployed in the area 500 m × 500 m is considered as MSN. This definition can be further modeled as $\forall$ k Λ k $\in$ N, $|D(k - AP/BS)| < R_k$, where k is an MN and $D(k - AP/BS)$ is the distance between an MN and AP/BS.

Definition 2 (large scale network (LSN)) If any of the MN does not have a direct communication with the end node or the end node is available more than one hops away from the MN. Thus, if the number of hops between the MN and end node is more, the network is considered as Large Scale Network (LSN). The definition can be further modeled as $\exists$ k Λ k $\in$ N, $|D(k - AP/BS)| > R_k$, where k is the AP/BS among the set of '*N*' and $D(k - AP/BS)$ is the distance between the k and the AP/BS where end node is connected.

3.3 Handover triggering phase

In order to clearly elaborate the working of the proposed handover triggering phase, a scenario is considered, where an MN is moving along a straight road surrounding by a long-range cellular BSs and short range WIFI APs. The speed of the MN is constantly ranging between lower and upper limit (1 and 15 m/s). The WIFI APs are randomly deployed in the coverage area of a cellular BS. The MN always performed scanning of available network when following two conditions hold 1) the expected time ($E[t_{AP}]$ or $E[t_{BS}]$-The time to cover the coverage area of an AP or BS) drops below a threshold $\theta[Th_1]$ and 2) there does not exists any cellular BS. Traditional approaches are always prefer a WIFI AP over a cellular BS. But, the WIFI interface always required high energy compared to the other network interfaces. Therefore, preferring a WIFI interface for communication drains the battery eventually. Similarly, the proposed triggering mechanism presents a novel approach of initiating handover based on the expected time require by the MN in the coverage area of an AP/BS.

The expected distance ($E[d_{BS}]$) covered by the MN in the coverage area of a cellular BS depends on the density (ρ) and the area (A) covered by the APs. Similarly, the distance between two consecutive WLAN APs is considered as the coverage area covered by both the APs and is represented by $Z_{i,\ i+1}$ follows a negative exponential distribution with a rate parameter λ_a having a probability density function (PDF) $f(d) = \lambda_a e^{-\lambda_a d}$ and cumulative density function (CDF) $F(d) = 1 - e^{-\lambda_a d}$. These assumptions have been used for real time measurements of vehicular as well as pedestrian movements in the WLAN AP and cellular BS coverage areas [7]. Similarly, it is also widely adopted in different research studies for the theoretical and analytical analysis [35]. The user is moving with a speed v follows a Poisson distribution having a rate parameter λ_b, based on this assumption the probability of n AP arrivals in time t is defined as $P(N,\ t) = (\lambda_b t)\ \frac{N e^{-\lambda_b t}}{N!}$. Moreover, the AP arrival rate λ_b (The rate at which APs appears to an MN) depends on the radius (r) of a WLAN AP, v, and ρ i.e. $\lambda_b \cong 2rv\rho$.

The distance covered (d_{BSc}) by the MN while it is remain attached with the current BS, depends on the scanning time (t_α) plus the total time in the coverage area of a BS (T_{BSc}) and the speed of the MN v i.e. $d_{BSc} = v \times \Delta t$ *where* $\Delta t = t_\alpha + T_{BSc}$ as shown in Fig. 3 (the shaded area represents the coverage area of an AP or BS). Similarly, the expected distance covered ($E[d_{BSc}]$) by the MN depends on the ρ, as well as the A covered by these APs as shown in following Eq. 5.

$$E[d_{BSc}] = \sum\nolimits_{N=1}^{\infty} N d_{BSc}(A_i \rho) \quad where\ \ i = 1, 2, 3 \cdots k \tag{5}$$

Where k is the total number of APs available in the coverage area of a cellular BS.

The density of the APs is directly proportional to the AP arrival rate. Therefore, by putting the values of d_{BSc} and ($A_i\rho$) in Eq. 5, we get Eq. 6 as follows [41].

$$E[d_{BSc}] = v\Delta t\ \left(1 - e^{-\lambda_b \Delta t}\right) \sum\nolimits_{N=1}^{\infty} N e^{-\lambda_b (N-1)\Delta t} \tag{6}$$

Similarly, the WLAN coverage is equal to the distance by a particular set of APs in a region. Thus, the expected WLAN AP coverage ($E[d_{APc}]$) depends on the radius covered by an AP and the expected distance between the two consecutive APs as shown in following Eq. 7.

$$E[d_{APc}] = 2r + E[d_{zAPc}] \tag{7}$$

Where z represent the distance between two consecutive APs. By putting the value of $E[d_{zAPc}]$ in Eq. 7, we get Eq. 8 as follows.

$$E[d_{APc}] = 2r + \sum\nolimits_{N=1}^{\infty} N E\left[z \middle| z < 2r\right] P(z < 2r)^n P(z > 2r) \tag{8}$$

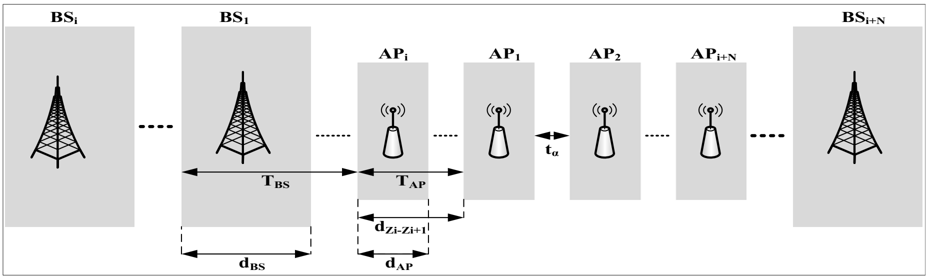


Fig. 3 The working of the proposed handover triggering approach

Where $E[z|z < 2r] = \frac{\int_0^{2r} zf(z)dz}{P(z<2r)} = \frac{-2re^{-2r\lambda_c}+\frac{1}{\lambda_c}-\frac{1}{\lambda_c}e^{-2r\lambda_c}}{1-e^{-2r\lambda_c}}$ [7]. Similarly, λ_c represents the arrival rate of new APs, $P(z < 2r) = F(r) = 1-e^{-2r\lambda_c}$ and $P(z > 2r) = 1-F(2r) = e^{-2r\lambda_c}$

Once the expected coverage area of the cellular BS and WLAN AP is computed, the next step is to identify the handover triggering place. When the MN enters into the coverage area of a BS, it periodically scans the available networks. However, using periodic scanning requires high energy compare to the adaptive scanning technique. Therefore, to optimize the working of proposed handover triggering technique and select the appropriate place for initiating handover, we first define the expected coverage area of both the WLAN AP and cellular BS. Once, we know the expected distance covered by an MN in the coverage area of a WLAN AP and cellular BS, the next step is to compute the expected time ($E[t_{BS}] = \frac{E[d_{BSc}]}{v}$) required to cover the expected coverage distance in a BS coverage area as follows.

$$E[t_{BS}] = \Delta t \left(1-e^{-\lambda_b \Delta t}\right) \sum_{N=1}^{\infty} N e^{-\lambda_b (N-1)\Delta t} \tag{9}$$

Similarly, the expected time ($E[t_{AP}] = \frac{E[d_{APc}]}{v}$) required to cover the distance in an AP coverage area is computed as follows.

$$E[t_{AP}] = \frac{2r + \sum_{N=1}^{\infty} NE\left[z \middle| z < 2r\right] P(z < 2r)^n P(z > 2r)}{v} \tag{10}$$

After calculating the values of $E[t_{BS}]$ and $E[t_{AP}]$, the next step is to define the threshold ($\theta[Th_1]$) on the minimum time required to initiate a handover process, select a network, and execute the handover process. According to International Telecommunication Union (ITU), the time require to complete a handover process should be less than 150 ms and the maximum packet loss should be less than 3% [33]. Keeping these two limits in mind, we define a threshold when the MN covers 75% of the expected distance (3/4 of the $E[t_{BS}]$ and $E[t_{AP}]$). After the calculation of $E[t_{BS}]$ and $E[t_{AP}]$, the MN compares the values of $E[t_{BS}]$, $E[t_{AP}]$ and $\theta[Th_1]$. If the difference is less than the threshold $\theta[Th_2]$ ($\theta[Th_2] = E[t_{BS}]$ or $E[t_{AP}] - \theta[Th_1] + R$ where R (random amount of time) depends on WLAN AP and cellular BS's coverage area), then the MN speed up of the scanning process by R. Similarly, if the difference is more than the $\theta[Th_2]$, the MN slows down the scanning process by R. Thus, it makes the proposed handover triggering technique of a dynamic nature. This dynamicity makes the proposed triggering technique more efficient and energy aware for vertical handover management in heterogeneous wireless networks.

3.4 Network selection phase

Once the handover is triggered the next phase is to select an optimal network for handover among other networks. The target network selection is carried out by using Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). Recently, researchers show that the TOPSIS decision model has remarkable results in selecting the best network among available networks for handover [6]. Similarly, in the case of heterogeneous wireless networks, the TOPSIS is the most advanced technique for categorizing the networks on the basis of different parameters. However, the input to a TOPSIS decision model needs a Fuzzy-based technique to remove the unnecessary information from the input parameters. Therefore, we first used a Fuzzy Rule Based (FRB) system to filter out those networks which are not satisfying the QoS criteria. Thus, it highly reduced the processing time and choosing of a network during a handover process. We proposed seven different parameters for selecting the target network among the available networks. These parameters include delay (α), jitter (β), Bit Error Rate (BER) (γ), packet loss (δ), communication cost (c), response time (σ), and network load (ω). The network which provide with the minimum output of all the proposed parameters is selected for the network selection process. The fuzzified values are then passed to the decision process to decide a network based on the FRB. The process of selection of an optimal network based on Fuzzy based TOPSIS MADM decision model is shown in the following Fig. 4.

3.4.1 FRB based elimination of inappropriate networks

The FRB system obtains the input parameters and returns the appropriate networks for network selection. The membership function is used to convert these raw values to the member's values. It is designed based on the input parameters using triangular membership function with three regions i.e. low, medium, and high. In addition, increasing the regions also increases the complexity of the membership function. Each input parameters P is tested in the available regions. In each region, the starting and ending points, upward and downward slopes, and the relative distances of eachpoint lies in the region from P is represented using P_s and P_e, m_u and m_d, d_1 and d_2, respectively. All of the regions are shown in Fig. 5a, b, and c with above-mentioned parameters.

In order to separate the QoS level of each application, various traffic classes have been defined by the ITU. The intensity of each parameter towards the corresponding traffic class is defined in the following Table 1. With three regions and seven different input parameters the total rules becomes $3^7 = 2187$ possible rules. The input parameters are used to decide whether a rule is applicable or not. However, the rank of the available networks that are suitable for deciding whether a network is appropriate enough to pass it to a decision function is given by the centroid value (C) of a region and the area of the region (A). The output network is given by following function incorporating the parameter P_i.

$$P_i = \frac{\sum A_i \times C_i}{\sum C_i} \tag{11}$$

In the following sections, we explain the working of the TOPSIS decision model in the proposed network selection scheme.

3.4.2 Constructing decision-making matrix

In order to get the ranking of the available networks in a heterogeneous wireless network environment. The TOPSIS method starts with arranging the parameters obtain from different

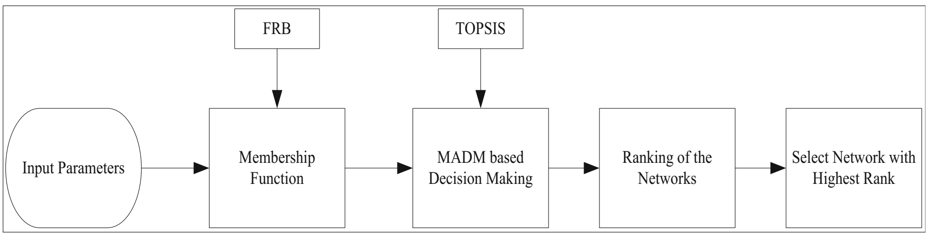


Fig. 4 The working of the proposed fuzzy-based network elimination process

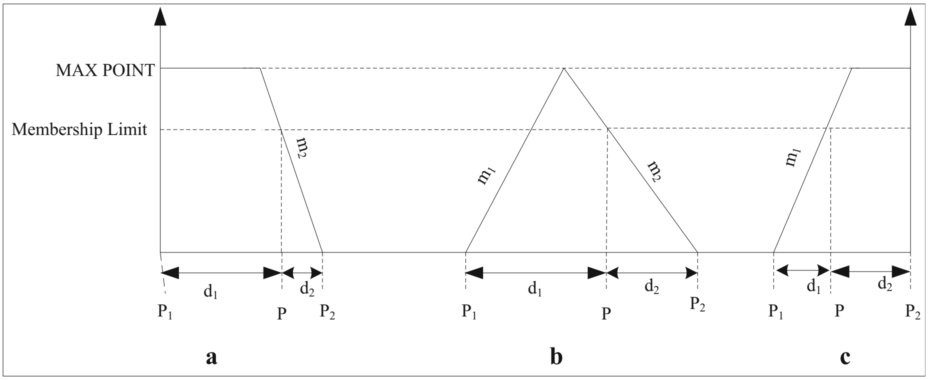


Fig. 5 Triangular member functions with three regions

networks in a decision matrix. The rows of the matrix represent the parameters of a particular network, and the column represents a parameter in each network. Moreover, we integrate the TOPSIS method with the MADM method to make the TOPSIS process as fast as possible. Because, the time between the handover initiation and execution is very short and thus performing the decision and ranking of the available networks get increases with the arrival of AP or BS. Moreover, the integration of TOPSIS with MADM results in improving the

Table 1 Sensitivity of a parameter over another parameter in different traffic classes

α	β	γ	δ	c	σ	ω
Conversational						
1	1/3	5	3	3	4	4
3	1	5	4	4	5	5
1/5	1/5	1	1/3	2	2	3
1/3	1/4	3	1	3	3	4
1/3	1/4	1/2	1/3	1	3	3
1/4	1/5	1/2	1/3	1/3	1	1/3
1/4	1/5	1/3	1/4	1/3	3	1
Background						
1	1/2	4	2	2	3	3
2	1	4	4	3	4	4
1/4	1/4	1	1/2	2	1/2	3
1/2	1/4	2	1	2	3	2
1/2	1/3	1/2	1/2	1	2	3
1/3	1/4	2	1/3	1/2	1	2
1/3	1/4	1/3	1/2	1/3	1/2	1
Interactive						
1	1/3	3	3	4	4	4
3	1	4	5	4	5	5
1/3	1/4	1	1/3	3	1/3	4
1/3	1/5	3	1	3	2	4
1/4	1/4	1/3	1/3	1	3	4
1/4	1/5	3	1/2	1/3	1	3
1/4	1/5	1/4	1/4	1/4	1/3	1
Streaming						
1	1/3	4	5	4	5	5
3	1	5	5	4	5	5
1/4	1/5	1	1/3	4	1/4	5
1/4	1/5	3	1	3	3	4
1/4	1/4	1/4	1/3	1	4	5
1/5	1/5	4	1/3	1/4	1	4
1/5	1/5	1/5	1/4	1/5	1/4	1

performance of the proposed scheme. Let $N_1, N_2 \ldots N_n$, represents the networks available in a heterogeneous scenario, and M denotes the decision-making matrix as shown below.

$$M\left(x_{ij}\right) = \begin{array}{c} \begin{array}{ccccccc} \mathrm{P}_1 & \mathrm{P}_2 & \mathrm{P}_3 & \mathrm{P}_4 & \mathrm{P}_5 & \mathrm{P}_6 & \mathrm{P}_7 \end{array} \\ \left[\begin{array}{ccccccc} \alpha_{11} & \beta_{12} & \gamma_{13} & \delta_{14} & c_{15} & \sigma_{16} & \omega_{17} \\ \alpha_{21} & \beta_{22} & \gamma_{23} & \delta_{24} & c_{25} & \sigma_{26} & \omega_{27} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \alpha_{m1} & \beta_{m2} & \gamma_{m3} & \delta_{m4} & c_{m5} & \sigma_{m6} & \omega_{mn} \end{array}\right] \end{array} \begin{array}{c} \mathrm{N}_1 \\ \mathrm{N}_2 \\ \\ \mathrm{N}_\mathrm{m} \end{array} \tag{12}$$

Let $P_j^* = max_{1 \le i \le m}(x_{ij})$ and $P_j^\circ = min_{1 \le i \le m}(x_{ij})$ denote the maximum and minimum value of a parameter in a network, respectively. Then it is important to normalize the decision matrix in order to preserve the relative order. The normalization is done through linear scaling in which distance of each parameter in a network is checked from the maximum ($x_{ij}^* = {}^{x_{ij}}/_{P_j^*}$) and minimum ($x_{ij}^* = {}^{x_{ij}}/_{P_j^\circ}$) value. The normalized matrix $\mathrm{M}^*(\mathrm{x_{ij}})$ is shown below.

$$M'\left(x_{ij}\right) = \begin{bmatrix} \alpha_{11}^* & \beta_{12}^* & \gamma_{13}^* & \delta_{14}^* & c_{15}^* & \sigma_{16}^* & \omega_{17}^* \\ \alpha_{21}^* & \beta_{22}^* & \gamma_{23}^* & \delta_{24}^* & c_{25}^* & \sigma_{26}^* & \omega_{27}^* \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \alpha_{m1}^* & \beta_{m2}^* & \gamma_{m3}^* & \delta_{m4}^* & c_{m5}^* & \sigma_{m6}^* & \omega_{mn}^* \end{bmatrix} \tag{13}$$

Where the superscript (*) is used to represent the value of a parameter after normalization.

In order to determine the negative and positive ideal situation of a network, every parameter of the network must be assigned a particular weight. These positive and negative ideal situations further help in the selection process of an optimal network. In general, the more a network have a positive situation the more it is good for the handover. Similarly, the weighted normalized matrix ($M^{''}$) is constructed from $M^{'}$ by assigning each parameter with a particular weight, in order to determine negative and positive ideal situation. We also give a user with the functionality to selects its own weight. But, if a user is unable to select its own weights then the default weights are applied. The weight of a parameter is selected on the basis of priority of a parameter. Therefore, the user define a profile for the priorities of the parameters used for network selection. The prority of a parameter represents the importance of the parameter. Let take an example to clearly elaborate this approach, a user may have preferred a target network providing with an energy efficient handover for one application over another, whereas another user may prefer a network which providing highest data rate for the same application. Sometimes, a user may using an application which require less bandwidth like a file transfer application, in this case a, user may select a network with less bandwidth while the same user when running a video streaming application may prefer a network with higher bandwidth. Each parameter is assigned with a value from 0 (very low) to 7 (very high). The weight (w) of a parameter is computed as $w_p = {}^{p}/_{\sum_{i=1}^{7} p_i}$, where $\sum_{i=1}^{7} w_i = 1$.

$$M'\prime\left(x_{ij}\right) = \begin{bmatrix} w_1\alpha_{11}^* & w_2\beta_{12}^* & w_3\gamma_{13}^* & w_4\delta_{14}^* & w_5c_{15}^* & w_6\sigma_{16}^* & w_7\omega_{17}^* \\ w_1\alpha_{21}^* & w_2\beta_{22}^* & w_3\gamma_{23}^* & w_4\delta_{24}^* & w_5c_{25}^* & w_6\sigma_{26}^* & w_7\omega_{27}^* \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ w_1\alpha_{m1}^* & w_2\beta_{m2}^* & w_3\gamma_{m3}^* & w_4\delta_{m4}^* & w_5c_{m5}^* & w_6\sigma_{m6}^* & w_7\omega_{mn}^* \end{bmatrix} \tag{14}$$

3.4.3 Computing ideal situation

As we know, that all the parameters considered for the network selection is indirectly proportional to QoS of that network, therefore, the maximum and minimum value in each column of matrix $M^{''}$ represent the negative (I^-) and positive (I^+) ideal situation, respectively. These situations are computed using following Eqs. 14 and 15.

$$I^+ = \left[\left(\min_i z_{ij} \middle| j \epsilon J\right)\right] = \left[p_1^*, p_1^*, \cdots, p_7^*\right] \tag{15}$$

$$I^- = \left[\left(\max_i z_{ij} \middle| j \epsilon J\right)\right] = \left[p_1^\circ, p_2^\circ, \cdots, p_7^\circ\right] \tag{16}$$

where J = 1, 2, 3,…,7

Once the positive and negative situations are identified then it is necessary to compare it with a hypothetical ideal situation. Because, TOPSIS does not provides the functionality of arranging each parameter according to their distance from the hypothetical ideal situation. It is the functionality of the MADM decision modeling that the best parameter must be closest to the hypothetical ideal situation and worst parameter must be farthest from it. Therefore, it is important to calculate the distance of each parameter from the positive ideal situation (H^+) and negative ideal situation (H^-) by integrating MADM decision modeling in the TOPSIS process. This computation is carried out using Eqs. 17 and 18.

$$H_i^+ = \sqrt{\sum_{k=1}^{7} \left(m''_{ik} - p_k^*\right)^2}, i = 1,\ 2, \cdots, m \tag{17}$$

$$H_i^- = \sqrt{\sum_{k=1}^{7} \left(m''_{ik} - p_k^\circ\right)^2}, i = 1, 2, \cdots, m \tag{18}$$

The explanation of the negative and positive ideal situation is explained in Fig. 6.

3.4.4 Optimal network selection

Finally, we calculate the relative approach degree (R*). The R* helps in finding the optimal network for handover. It is calculated using Eq. 19.

$$R_i^* = \frac{H_i^-}{H_i^+ + H_i^-} \tag{19}$$

If there are multiple networks available in the heterogeneous environment then it necessary to calculate the R* of each network and then sort it to get the optimal network with the highest degree. Let make it more simplify by using following cases.

$$\begin{aligned}
&\text{If } N_i = I^+, \text{ then } H_i^+ = 0, \text{ and RAD becomes } R_i^* = 1\\
&\text{If } N_i = I^-, \text{ then } H_i^- = 0, \text{ and RAD becomes } R_i^* = 0\\
&\text{If } N_i \rightarrow I^+, \text{ then } H_i^+ = 0, \text{ and RAD becomes } R_i^* \rightarrow 1
\end{aligned}$$

So from all of the above cases, we conclude that $0 \le R_i^* \le 1$. Thus once we get the R* of each network, we will arrange it in the order of N_i depending on R_i^*.

The working of the proposed network selection based on TOPSIS and MADM decision modeling is shown in Algorithm 1.

Algorithm 1: Working of proposed Network Selection based on TOPSIS and MADM

1: Initialization of decision-making Matrix M_{rc} (r = rows, c = cols)

$$M_{rc} = {}^{P_{ij}}\Big/\sqrt{\textstyle\sum_{r=1}^{m} {P_{rc}}^2 \quad r = 1, 2, \cdots, m; c = 1, \cdots, n}$$

2. Computing the Normalizing Matrix M'

$$P_c^* = max_{1 \le r \le m}(p_{rc})$$
$$P_c^{\circ} = min_{1 \le r \le m}(p_{rc})$$

3. Computing the Weighted Normalized Matrix M''

$$M''_{rc} = w_c * M'_{rc}, r = 1, 2, \cdots, m; c = 1, \cdots, n$$
$$w_p = {}^{p}\Big/_{\sum_{i=1}^{7} p_i}$$

3. Computing the Ideal Situation I

$$I^+ = (\min\ M''_{rc}\ c \in C \mid r = 1, \cdots, m = [z_r^+, z_{r+1}^+, \cdots, z_m^+]$$
$$I^- = (\max\ M''_{rc}\ c \in C \mid r = 1, \cdots, m = [z_r^+, z_{r+1}^+, \cdots, z_m^+]$$

4. Distance with Hypothetical Ideal Situation D

$$D_i^+ = \sqrt{\textstyle\sum_{k=1}^{n}\left(m''_{kc} - m''^{+}_{k}\right)^2}, k = 1, 2, \cdots, m$$
$$D_i^- = \sqrt{\textstyle\sum_{k=1}^{n}(m''_{kc} - m''^{-}_{k})^2}, k = 1, 2, \cdots, m$$

5. Computing the Relative Approach Degree

$$R_i^* = \frac{D_i^-}{D_i^+ + D_i^-} = 0 \le R_i^* \le 1\ ; i = 1, \cdots, m$$

4 Results and discussion

We evaluate the working of the proposed scheme against the SAW, WPM, GRA, VIKOR, and ELECTRE decision model. Similarly, the proposed coverage area based handover triggering technique is tested against the fixed RSS and adaptive RSS triggering approaches. The performance of the proposed scheme is tested in three different type of mobility scenarios. In the first scenario, different numbers of MNs are sent to a high coverage area (high BS arrival rate - LSN) with high speed. In the second scenario, the same numbers of nodes are sent to

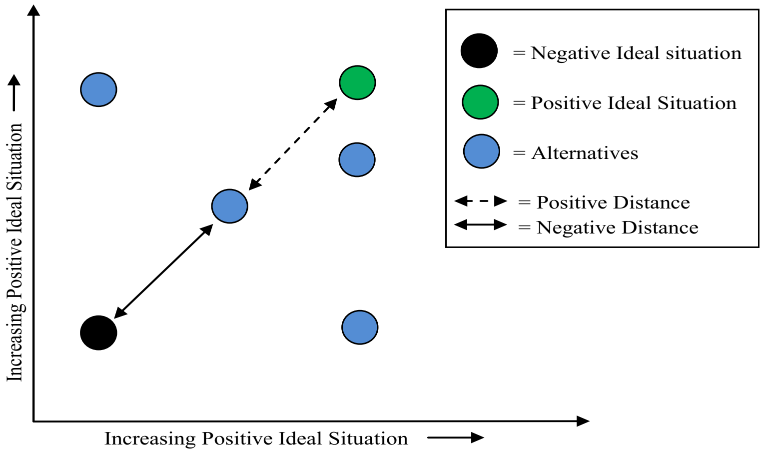


Fig. 6 Analysis of negative and positive ideal situation

smaller coverage area (High AP arrival rate - MSN) with low speed. In the third scenario, the two-time greater number of nodes are deployed in a heterogeneous networks environment (AP and BS arrival rate gradually increased – both LSN and MSN) with a speed of ranging from 0 to 30 m/s. Due to the coverage area difference of the WLAN, WiMAX, and Cellular network, the transmission power is taken as 100 mW (T_{AP}), 300 mW ($T_{WiMAXBS}$), and 250 mW ($T_{CellularBS}$), respectively [14]. The proposed scheme is tested on a different number of nodes ranging from 10 to 100. The number of applications is randomly assigned to each node during its creation and a user is able to close and open an application at any time during the simulation. Three different type of applications i.e. audio and video call (VoIP), multimedia streaming, and elastic is used by each MN during the simulation. The maximum time to run a particular application is set to 2 min. Thus, the MN runs as much as possible applications. The proposed scheme is simulated for a longer duration, in order to check its performance for a high number of handovers. Similarly, the RSS (fixed) received by the MN is computed using the relation, $RSS = 10{\cdot}\log_{10}\left(\frac{coverage\ \ area\ \ of\ \ underlying\ \ technology}{\left(d_{MN-AP/BS}\times 39.37\right)}^{2.5}\right)$ dBm, where $d_{MN\text{-}AP/BS}$ is the distance between the MN and the AP or BS [8]. The coverage area of WLAN, WiMAX, and cellular technology is set to 100, 1000, and 500 m. Moreover, the adaptive RSS is measured using Eq. 1. The rest of the simulation parameters is listed in Table 2.

The initial values are manually assigned to each network from Table 3. The MN first set their initial profile from these values before starting a movement in the heterogeneous wireless networks. The communication cost has taken on the basis of the architecture of the underlying technology. In the case of UMTS, its value is high and similarly low in the case of WIFI because it is a low-cost and easily accessible technology. Although, it is also changed with the nature of the context of a user, for example, sometimes a user is more interested in cost than coverage of a network. The initial response time is kept low and as a number of nodes join the network, it is gradually increased. The values of delay, jitter, BER, and packet loss is taken from [17].

The MNs performed several hundred handovers. Similarly, it is running different applications during each handover. We considered a heterogeneous network environment with three different types of network i.e. UMTS, WIFI, and WiMAX as shown in Fig. 7. Initially, the MN

Table 2 Simulation parameters

Parameter	Value
Simulation duration	2 h
Topology size	5000 (m) × 5000 (m)
Number of MNs	1 ~ 100
MN's movement (v)	Rectilinear movement at 0 ~ 30 m/s
T_{AP}, $T_{CellularBS}$, $T_{WiMAXBS}$	100 mW, 250 mW, 300 mW
WLAN AP coverage	100 m
Cellular BS coverage	500 m
Cellular BS coverage	1000 m
Data rate (Elastic, audio call, streaming)	50, 70, 128 Kbps
Scanning duration (T_s)	10 ms
Network scanning (E_s)	13.7 mJ
$\boldsymbol{\theta}[\boldsymbol{Th}_1]$	75% of ($E[t_{BS}]$ or $E[t_{AP}]$)
$\boldsymbol{\theta}[\boldsymbol{Th}_2]$ (in the case of WLAN AP)	($E[t_{AP}]$ - $\theta[Th_1]$) + (3 ~ 5 s)
$\boldsymbol{\theta}[\boldsymbol{Th}_2]$ (in the case of Cellular and WimMAX BS)	($E[t_{BS}]$ - $\theta[Th_1]$) + (5 ~ 15 s)
AP arrival rate (λ_b)	4 ~ 10 × 10^{-3} APs/m
Total battery capacity (Li-ion)	5 Wh

Table 3 Initial values of each criterion in a network

	Communication cost %	Network load (kbps)	Response time (sec)	Delay (ms)	Jitter (ms)	Bit error rate %	Packet loss (per 10^6)
UMTS	100	100	0.04	300	50	2	100
802.11n	10	80	0.03	150	30	1	20
WiMAX	40	70	0.035	100	20	0.5	15

is connected with AP1. The MN starts movement in the direction of the BS_w1, AP4, and Ap5. The MN checking the coverage area of the AP1, if it drops below than the predefined threshold $\theta[Th_1]$, it initiates handover. Moreover, the network selection scheme is invoke to rank the available networks. The BS_w1 has highest rank for the current applications running on MN's device as shown in Table 3, and thus the MN selects BS_w1 for handover. We tested the handover of an MN in three different type of networks, therefore, the network with high, medium, and low ranks are assigned with a value 1, 2 and 3, respectively. The ranking of the available networks is calculated and the results of the first six handovers are delineated in Table 4.

The MN calculates the rank of the available networks while considering the requirements of the application running over the MN's device during a handover process. In the case of the first handover, the MN is running a web browsing application which normally requires less bandwidth comparing to other applications. During the handover process, the MN computed the rank of the available networks (BS_w1, AP4, AP3). The rank of BS_w1 is higher than all of the other networks, therefore, the MN perform handover to BS_w1. This process is repeated for initial six handovers and the MN always performs handover to the network with the highest rank as shown in Fig. 7.

The handover time is one of the most important factors and its value highly affects a handover process. For example, if the MN is taking longer time during a handover process, then there are greater chances of disconnection from the current network. Moreover, the connection stability and

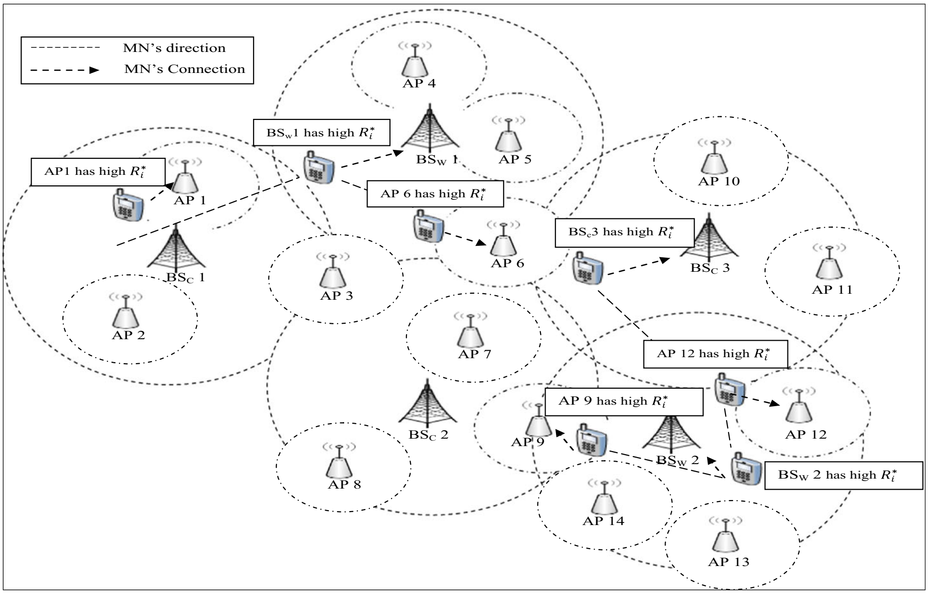
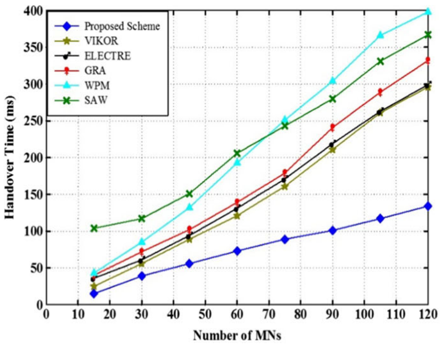


Fig. 7 Simulation scenario

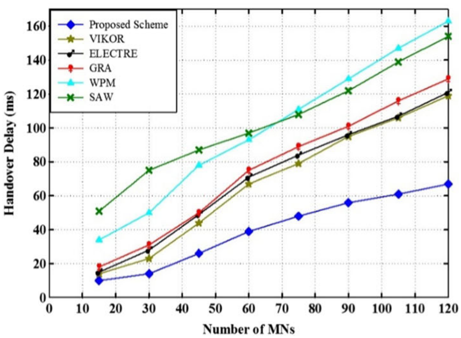
Table 4 Calculation of the ranks of the available networks during first six handovers

	VoIP	Streaming	Elastic		VoIP	Streaming	Elastic
First handover (web browsing)				Fourth handover (chatting)			
BS_w 1	1	2	1	AP 12	2	3	1
AP 4	3	2	2	BS_w 2	3	3	2
AP 3	2	3	3	BS_c 3	3	3	1
Second handover (VoIP)				Fifth handover (multimedia streaming)			
AP 6	1	2	1	BS_w 2	2	2	1
AP 5	2	3	3	AP 12	3	3	2
BS_c 2	3	3	2	AP 13	3	3	2
Third handover (streaming)				Sixth handover (VoIP)			
BS_c 3	2	3	1	AP 9	1	1	1
AP 7	3	2	2	BS_w 2	2	3	1
AP 10	2	3	2	AP 14	2	2	1

QoS of a network has an indirect proportion to the handover time [23]. As stated in Section 3.3, the maximum time allowed to perform a handover is 150 ms. In Fig. 8a, the handover time required by the GRA, VIKOR, and ELECTRE is somewhat similar but in the case of SAW and WPM it is relatively high. The proposed required very less time because of the proposed handover triggering technique. The results also show that the proposed handover triggering technique is not affected by the problems shown in Fig. 2. Similarly, in Fig. 8b, when more than 120 MNs join a network the handover delay exceeds 150 ms in the case of SAW and WPM. But, in the case of the proposed scheme, GRA, VIKOR, and ELECTRE, the handover delay is remained less than 150 ms. However, the proposed scheme shows significantly less delay than the rest of the schemes. We performed several experiments to test the performance of the proposed scheme against the SAW, WPM, GRA, VIKOR, and ELECTRE decision model with a different number of handovers and different speed of MNs as shown in Fig. 8a and b. During simulation, we gradually increase the number of MNs and analyze the handoff rate. The number of handovers in the case of VIKOR decision model is less than SAW, WPM, GRA, and ELECTRE decision models but more than the proposed scheme. While analyzing the results of proposed scheme and the rest of the schemes, we found that the number of frequent handovers in the case of SAW, WPM, GRA, VIKOR, and ELECTRE is very high comparing to proposed scheme. Similarly, the packet loss is significantly controlled due to the unnecessary handovers as shown in Fig. 9b. Initially, all the schemes except the proposed scheme behave similar but once the MN's speed exceeds than 15 m/s, the packet loss is highly increased.

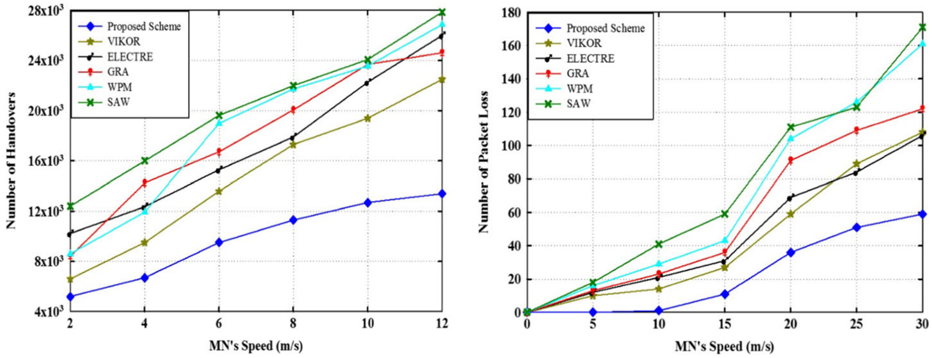


(a)



(b)

Fig. 8 **a** Handover time. **b** Handover delay

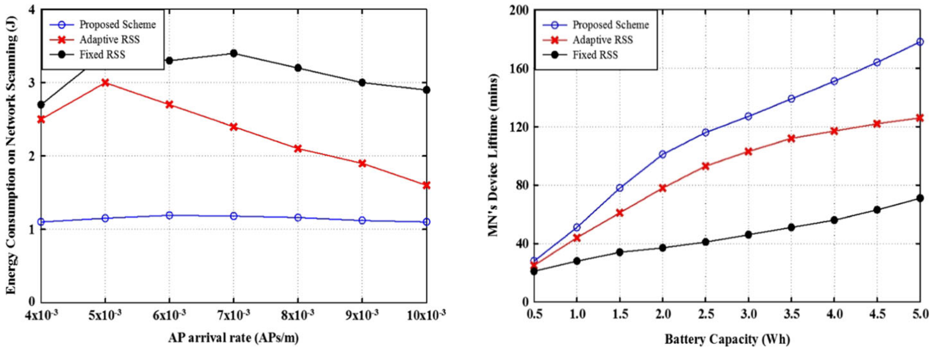


(a) (b)

Fig. 9 **a** No. of handovers. **b** Packet loss

The scanning period directly affects the energy consumption of the MN. If the MN perform frequent scanning, the energy consumption rate is highly increased. Assuming an MN which consumes 13.7 mJ energy per network scan, then after m time scans, the MN can consumes $m \times 13.7mJ$ energy. If we consider the same rate and the battery power of the MN is equal to 2.8728×10^5 J (7.98 Wh modern smartphone Li-ion batteries), then the battery can be drain completely only on scanning (using one interface) in $\left({}^{28728000}/_{m\times 13.7}\right)$ seconds. However, controlling the number of handovers, save the energy consumption wasted on the unecessary scanning.

The energy consumptuion of the MN on network scanning is tested against the AP arrival rate of APs. Initially, the adaptive RSS and fixed RSS method consume high energy but once the AP arrival rate increases the energy consumption on scanning is reduced as shown in Fig. 10a. Because, with the increase in number of APs in a region, the chances of getting connection with the approprite AP also increases. However, the proposed scheme is very less effected by the AP arrival rate. Because, the proposed scheme always initiate handover at the approprite place. Thus, the energy on uncessary scanning is highly reduced. Similarly, the device lifetime is significantly increased in the case of proposed scheme as shown in Fig. 10b. In the case of fixed RSS, the device energy is mostly consumed on the unecessary scanning and therefore the device battery drain eventually. Initially, the adpative RSS technique perform well but when the MN uses more applications then the battery life time decreases. In addition,



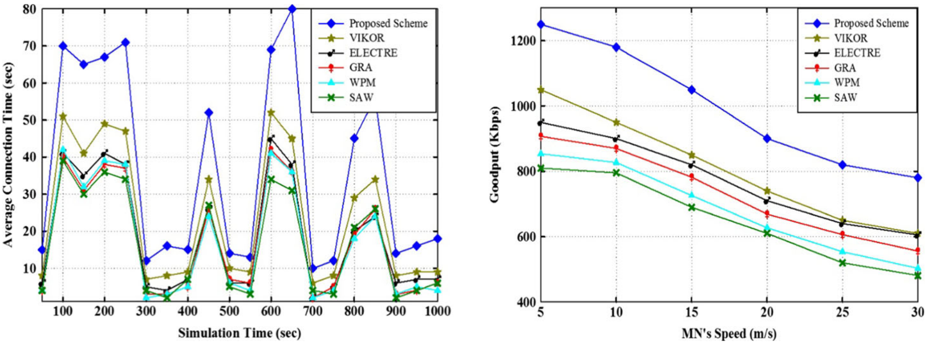
(a) (b)

Fig. 10 **a** Energy consumption on network scanning. **b** Device lifetime the adaptive RSS is also suffered from the wrong cell selection problem and therefore it consume most of the energy by frequent handovers. However, the proposed scheme perform better in all the cases and therefore it alleviates the battery lifetime.

The Average connection time (ACT) represents the time taken by the MN in a particular network. The ACT depends on the coverage area of the network. For example, if a network has high coverage area, the MN will remain connected for a longer time in the network. In Fig. 11a, the MN stays connected for a longer time with the cellular and WiMAX network. But, in the case of WIFI network, the MN connection time is less because the WIFI network has lower coverage area. The proposed scheme provides the appropriate network during handover and, therefore, the MN ACT is high. In the case of the other decision models, VIKOR performs better than SAW, WPM, GRA, and ELECTRE. However, the time is still less to get full advantage of the resources offered by a network. Whenever the MN connected for a lesser time in a network, it always degrades the goodput of a network. Moreover, if the speed of the MN is high, then there are greater chances of the MN to perform frequent handovers. The goodput of the proposed scheme is better than the other schemes because of performing less number of handovers and getting full advantage of the resources offer by a network as shown in Fig. 11b. Initially, the SAW, WPM, GRA, VIKOR, and ELECTRE offer better goodput but with the increase of the MN's speed the goodput decreases.

5 Conclusion

A handover decision scheme is either based on single or multiple criteria. The number of criteria is directly depending on the total handover time. Similarly, the time required for selecting a target network during handover is also increased with the increase in a number of parameters. Traditional handover decision approaches are mainly based on the single parameter. But, with the introduction of heterogeneous wireless networks, the performance of these single parameter decision schemes is highly reduced. Therefore, researchers introduce multi-criteria handover decision schemes. The complexity and processing of multi-criteria during handover is a complex job and hence these schemes require high handover time which ultimately leads to the high packet loss and even breaking of connection. Moreover, the schemes provided in the literature is based on several logical interfaces and modification to the existing systems. The IP-based solutions are more favorable than any other infrastructure, but the research consists of vertical handover schemes that are mostly



(a) (b)

Fig. 11 **a** Average connection time. **b** Goodput during handover based on lower layer architecture. Finally, deploying these schemes in heterogeneous wireless networks consume high power and suffered from high packet loss and handover time.

To cope with aforementioned constraints, we proposed a network selection model based on fuzzy based multi-criteria decision modeling. The decision of handover triggering is performed by computing the expected coverage area of the AP or BS. A multi-threshold mechanism is designed to trigger the handover at appropriate place and time. Moreover, the network selection is performed using fuzzy based TOPSIS with the MADM decision model incorporating several parameters such as delay, jitter, Bit Error Rate, packet loss, communication cost, response time, and network load. We consider only those parameters which are indirectly proportional with the QoS of a network. The ultimate goal of considering only indirect parameters is to avoid the imbalance created due to the two different types of parameters (directly and indirectly affecting). The proposed scheme is tested in different heterogeneous scenarios and the results are compared with different decision models and handover triggering techniques. The handover latency, the number of handovers, and packet loss is significantly reduced and the goodput and ACT of the MN in a network are significantly increased due to the proposed handover triggering and network selection. The simulation results show that the proposed scheme perform superior to the schemes present in the current literature. In future, we will extend the work to a more complex heterogeneous scenarios.

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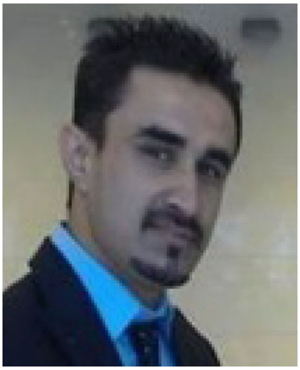

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