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An overview of intelligent selection and prediction method in heterogeneous wireless networks

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Abstract: Heterogeneous wireless access technologies will coexist in next generation wireless networks. These technologies form integrated networks, and these networks support multiple services with high quality level. Various access technologies allow users to select the best available access network to meet the requirements of each type of communication service. Being always best connected anytime and anywhere is a major concern in a heterogeneous wireless networks environment. Always best connected enables network selection mechanisms to keep mobile users always connected to the best network. We present an overview of the network selection and prediction problems and challenges. In addition, we discuss a comprehensive classification of related theoretic approaches, and also study the integration between these methods, finding the best solution of network selection and prediction problems. The optimal solution can fulfill the requirements of the next generation wireless networks.

Key words: heterogeneous wireless networks; network selection; network prediction; always best connected

1 Introduction

Wireless technologies have undergone a spectacular evolution over the past years, and the current trend is to adopt a global network of shared standards that can meet the requirements of user applications. A major step in the development of mobile communications is the introduction of wireless technologies. Cellular systems have evolved from first generation analog systems that only support speech services to current digital systems that support multimedia services. Wireless and mobile communications have also undergone dramatic development in the past two decades. Current mobile communications can support a wide range of applications and provide global coverage. Figure 1 illustrates the evolution of cellular communication and the IEEE standards area from the first generation (1 G) to the fourth generation (4 G) mobile networking.

Incorporating different wireless networks over an Internet protocol (IP) backbone is one of the aims of the architecture of next generation wireless networks (NGWNs). Various standards were operated to implement this vision. Examples include ITU in Recommendation ITU-R M.1645 [1] in June 2003, the IEEE 802.21 standard [2] (Jan 2009), and the access network discovery and selection function (ANDSF) [3] (2011). These standardizations attempt to calibrate the demands of interconnection between cellular wireless networks (LTE, UMTS, CDMA, and GSM) and IEEE standards (WiMAX, WiFi) to supply mobility support to users roaming between both systems. A suitable interworking solution is necessary to ensure seamless connectivity within the heterogeneous wireless environment. All existing solutions are built on the vision of all-IP based infrastructure, having IP as the common network layer protocol. The variety of applications (e.g., voice, VoIP, video, and data) by using different transport protocols (e.g., TCP, UDP) run on top of the IP layer, which in turn runs over a number of access technologies (e.g., cellular, WLAN, Ethernet).

Figure 2 shows that a heterogeneous wireless environment is multi-technology, multi-user, and multi-service and is an environment in which mobile users can easily move from one network to another. Such environment has several advantages, including utilizing already built infrastructure and eliminating the cost of deploying new technology. The environment further offers increased wireless capacity that guarantees backward capability, seamless mobility, and offers extra backing for low latency and high data rates. The increasing need for service delivery has increased the

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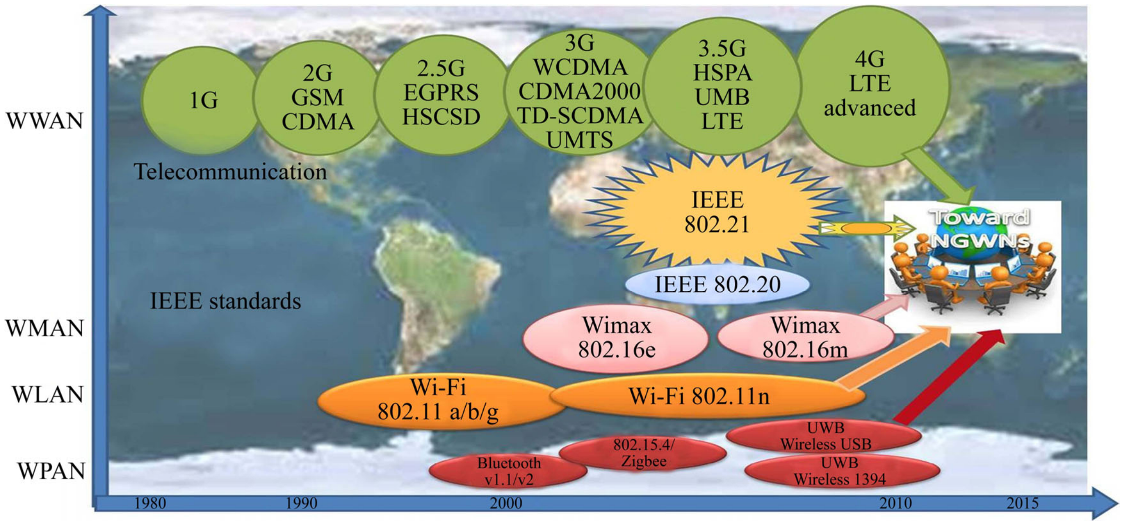

Fig. 1 Wireless networks evolution

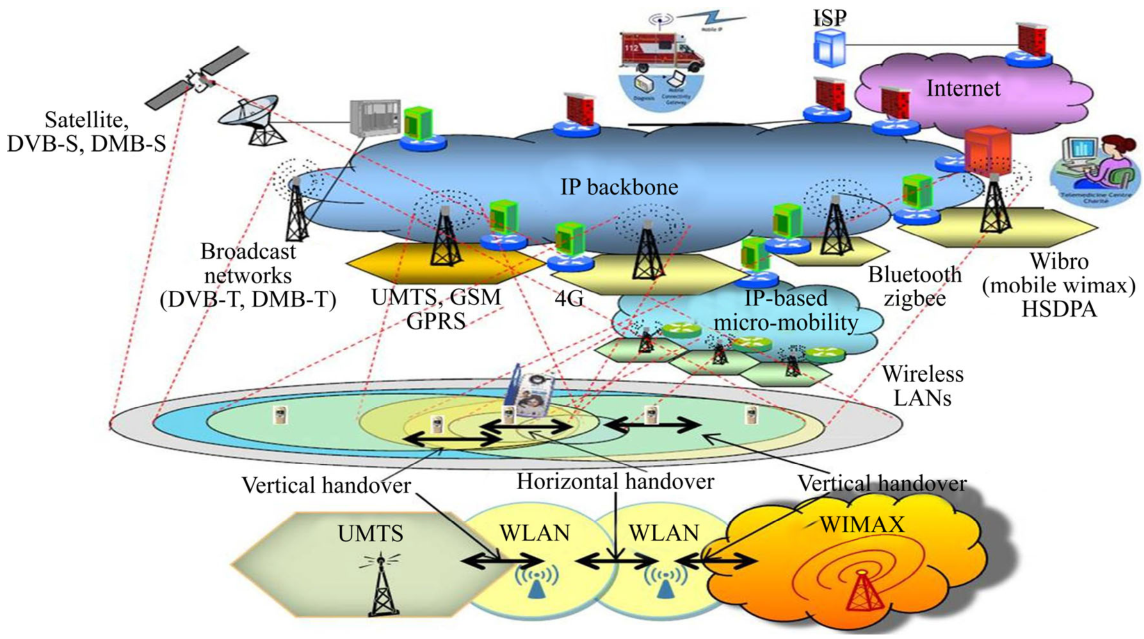

Fig. 2 Heterogeneous wireless environment

need for more wireless networks. This need is particularly noticed when considering high bit-rate multimedia applications that demand high quality of service (QoS) levels.

In this work, we introduce a literature review of various areas related to this research. We review important works related to the current study on network prediction and selection solutions in heterogeneous wireless networks (HWNs). Evolution of HWNs, is described in detail. Integrating HWNs results in the fulfillment of the requirements of next generation wireless networks (NGNs). Mobility management solution is likewise introduced. The challenges of the always best connected (ABC) requirement motivate researchers to propose and develop efficient network prediction and selection solutions. The network selection (NS) and prediction concepts, as well as providing a useful categorization of the theoretic approaches employed in the literature to model the network prediction and selection problems and their mapping to the NS problem, are also addressed in this work.

2 Evolution of next generation wireless networks

Although no clear definition of NGWNs exists, certain expectations on NGWNs exist, such as ubiquitous wireless communications, advanced user-centric multimedia services with high data rates and improved QoS, seamless services based on IP technology, and integrated heterogeneous wireless access networks. The key driving forces for the evolution include the demand for new services and applications, as well as the advancement of the Internet. Future services will be more user-centric and personalized. NGWNs are expected to support various existing wireless network technologies as well as new wireless technologies to support higher data rates of up to 1 Gbps. The network environment envisioned for NGWNs is composed of various wireless networks connected to a common NGWN core network. Figure 3 explains the typical setting of an NGWN. As the development toward NGNs is driven by the increasing mobile subscribers and mobile applications, mobility management is considered as an essential requirement for NGWNs. Also, another important requirements is to provide support for dynamic network prediction (NP) and network selection (NS). The NP and NS processes are completed initially at the time an application or a service is started and during the handover of the service to a new network.

3 Handover management

Handover management issues contain mobility scenarios, procedures, metrics, and decision algorithms. In terms of technologies, mobility scenarios can be classified into horizontal handover (HHO) between different base stations of the same technology and vertical handover (VHO) between different technologies. In homogeneous wireless networks, HHOs are usually required when the service access router becomes unavailable because of the mobile node (MN) movement. However, in HWNs, the need for VHOs can be initiated for the purpose of selecting the best network rather than connectivity reasons (e.g., according to user preference choice, supporting with high QoS). Figure 4 presents an example of the basic handover process for both VHOs and HHOs. Seamlessness and automation aspects in network switching are considered as the two important challenges that face the handover management process in HWNs. These particular requirements refer to the ABC concept that involves being connected to the best network in a heterogeneous wireless environment.

Mobile users may experience handovers because of changes in wireless link status. Alternatively, handovers may occur because of a gap in radio coverage as a result of mobile movement. For the stationary user, handovers may become imminent when the environment around the user changes, causing one network to become more attractive than another network. The user may select an application or a service that requires handover to a higher data rates channel, for instance, to download a large data

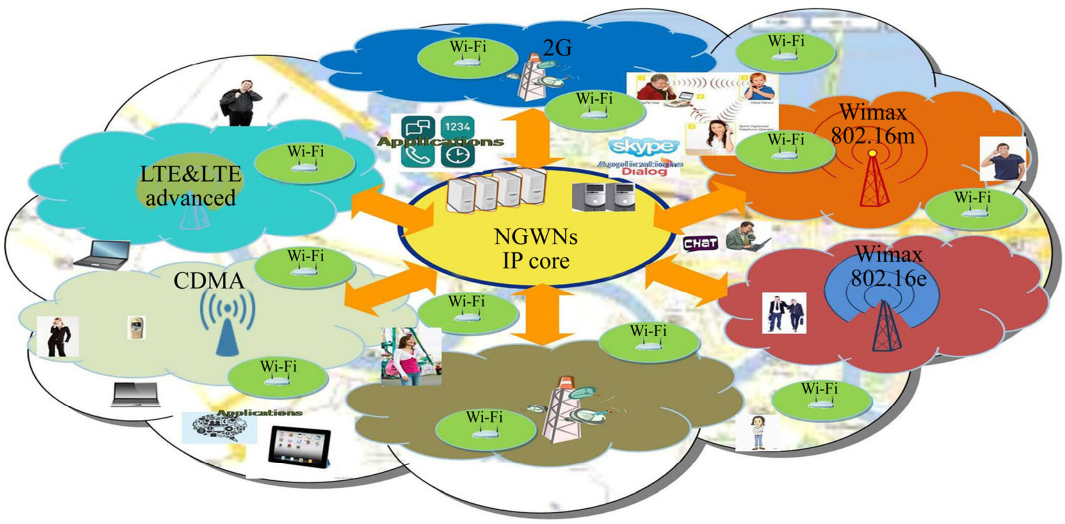

Fig. 3 Architecture of NGWNs

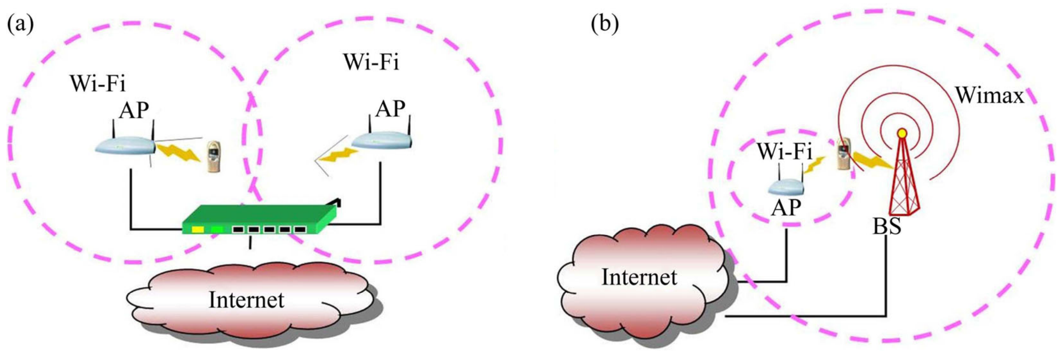

Fig. 4 Handover process for both vertical and horizontal handovers: (a) HHO; (b) VHO

file. Handovers must maximize service continuity, like network transition during a pause in a voice call to minimize any perceptible interruption in the service. In these cases, service continuity is defined as the continuation of service during and after the handover while minimizing aspects such as data loss and break time during handover without requiring any user intervention. The change in access network may or may not be noticeable to the end user, but should not require the user to re-establish the service. A change in service quality may occur as a consequence of the transition between various networks because of the varying capabilities and characteristics of the networks. For instance, if the QoS supported by a new network is unacceptable, higher layer entities may decide not to handover or terminate the current session after the handover on the basis of applicable policies. This specification lists essential elements that enable service continuity. Handover management consists of four main phases, namely VHO initiation, system discovery, VHO decision, and VHO execution [4], as illustrated in Fig. 5.

1) Handover initiation phase: The handover process is triggered by a number of criteria such as signal strength and link quality.

2) System discovery phase: In this phase, the MN collects all information required to identify and discover which neighbor networks can be adopted and what type of services can be provided in each network. These networks can also exchange information on QoS parameters for various services with the MN.

3) Handover decision phase: The MN decides whether connections should be continued by utilizing the available chosen network or to switch to another network. The decision might be taken considering various variables such as service type, monetary cost, available bandwidth, delay, jitter, packet loss, and user's preferences.

4) Handover execution phase: The connections are re-routed from the current network to another network in a smooth way. This phase also covers processes like authorization, authentication, and the transfer of context information as MN, which might be capable of communicating through an already existing network. As the handover execution process occurs, sufficient time will be provided for the network to accomplish essential functions while eliminating any service disruptions.

This work is mainly focused on the two phases of VHO, i.e., VHO initiation and decision phases. The VHO prediction process (how to avoid unnecessary handover) is part of the VHO initiation phase. The VHO selection process is a part of the VHO decision phase, which describes how the MN chooses the best network from various candidate networks. The correct decisions taken in these two phases will play a crucial role in the successful implementation of a seamless VHO.

4 Intelligent heterogeneous networks selection and prediction

Network prediction and selection are generally a continuous process of choosing the most suitable access network for a certain user to execute a certain operation. Consequently, these processes are the most significant steps because they influence the normal operation of mobile communication. This statement is particularly correct if the MN reaches a handover decision, in which many networks are available with diverse characteristics (parameters). These processes require efficient intelligent mechanisms to solve the problems of NP and NS. In the VHO prediction process, an efficient mechanism to avoid unnecessary handover is necessary. The main goal of the NS process is to determine the process of selecting the best network from different available networks that satisfy user requirements. In addition, an efficient algorithm to allocate different types of bearer services in HWNs can also improve network performance.

Generally, NP and NS problems are modeled by employing either a centralized or a decentralized approach [5]. Most centralized approaches are network-

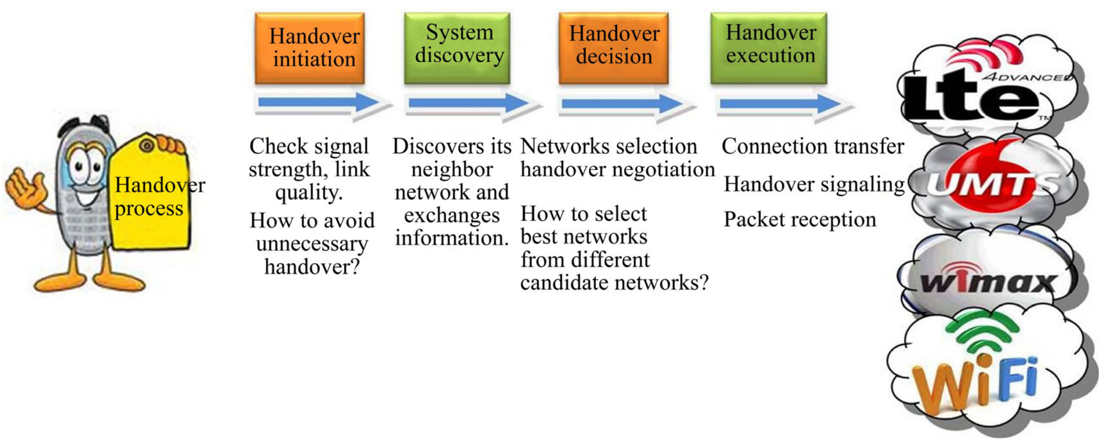

Fig. 5 Handover process

centric and consist of a centralized, operator-controlled policy that decides user distribution between networks. These network-centric approaches are based on the cooperation of subscribed user devices in following the decision reached by the network controller. However, in the decentralized approach, the decision is reached at the user side either by the user or automatically by the user's device. This automation may be based on policies or rules set by the user or downloaded to the user's device from an operator or service provider. A number of approaches considered as decentralized user-centric view the case of users who are not solely subscribed to one network, but instead have multiple subscriptions or agreements in place and wish their device to select the most acceptable candidate network.

In a homogeneous wireless environment, handover decision is considered as a handover initiation phase in the heterogeneous wireless environment. Handover initiation represents the decision whether to initiate handover and which cell to handover in cellular networks. Traditionally, the need for HHO emerges when the received signal strength (RSS) of the base station deteriorates below a certain threshold value. In a heterogeneous wireless environment, users can move among several different wireless networks. Users will benefit from various network characteristics (cost, power consumption, bandwidth, delay, jitter, packet loss, coverage, etc.) that cannot be compared directly. The VHO process shown in Fig. 2 becomes more complex in heterogeneous wireless environment compared to within a homogeneous wireless environment. Therefore, the handover decision is a challenging problem, and resolving this problem can influence handover performance. This process refers to a VHO prediction and decision, which require more criteria (not only RSS) as compared to HHO [6]. In this work, handover initiation refers to the decision to choose an appropriate moment to initiate handover. This review discusses how to avoid unnecessary handovers. The NS process in the handover decision phase likewise involves determining the most suitable network for the mobile user. The first choice can avoid unnecessary handovers, predict disconnections, and minimize signaling overhead. The second choice must satisfy user requirements by deciding which network to connect to when different networks are available for a specific service.

4.1 Heterogeneous wireless networks prediction

In a proactive handover in HWNs, the MN attempts to predict future conditions by evaluating measurable network parameters, like signal strength and link quality. Context information is automatically sent to the client without requiring explicit requests. Proactive mechanisms can reserve resources in advance on the basis of the knowledge of network parameters, such as topology, coverage, and positioning information. These mechanisms can be classified further into knowledge-based and modeling-based proactive handovers. The knowledge-based approach utilizes pre-recorded network coverage information together with an MN's location to predict the availability of different networks at a particular location. The modeling-based approach predicts future conditions through mathematical models. This approach is flexible in accommodating random MN movements and has the advantage of being easily adoptable to both simulated and real-time systems.

At any instant, the MN may fall under the coverage of several different networks that vary in physical, medium access, and link-layer characteristics [7] and that offer a variety of different services in heterogeneous wireless environments. Handovers are no longer executed to maintain connectivity during mobility. Instead, the entire process adapts a more opportunistic approach of deriving maximum benefit from all available networks. The main goal of VHO prediction techniques is to devise solutions that can minimize and even eliminate disruptions caused by handovers. Equipping the network and MN with the ability to detect VHOs proactively before they actually take place is an effective way to achieve this goal, so that the devices can begin with procedures to prepare and adjust to impending changes in network conditions.

Unnecessary handovers need to be eliminated for the success of VHOs in HWNs. These unnecessary handovers are mainly caused by the failure to recognize temporary coverage, the unavailability of required resources, and the congestion in the new network. The recognition of temporary coverage remains largely an unsolved problem. The situation becomes even more complicated with the consideration of random device mobility patterns [8]. The handover initiation is based on the assessment of RSS as a good indicator of network signal strength and link quality. In wireless networks, a rapid degradation in the value of RSS indicates that the MN is approaching the coverage boundary and may soon perform an imminent handover. A number of studies on the optimization of the MIH link going down (LGD) event have been carried out to address this issue. However, majority of the implementations depend on predefined thresholds, and most of these implementations utilize RSS as the metric in predicting handover. The LGD event is generated if the current RSS crosses a predefined threshold. Research on this prediction mechanism is summarized in Table 1.

Many studies have adopted the RSS as a key indicator of network availability. In wireless networks, a rapidly deteriorating value of RSS indicates that the MN is approaching the coverage boundary and may soon

Table 1 Proposed prediction mechanisms in HWNs

Reference	Objective	Event or trigger	Parameter	Particularity
[9−10]	Network prediction: Proposed predictive VHO mechanism implemented within IEEE 802.21.	LGD	RSS, QoS metrics [9]; RSS [10]	Adaptive and accurate LGD trigger time control provides low VHO cost in terms of the service disruption time and the total handover time.
[11]	Network prediction: Proposed MIH VHO mechanism that defined certain RSS thresholds and probability confidence to trigger LGD event.	LGD	RSS	The proposed mechanism provides better VHO efficiency and reduces the VHO delay and possible packet loss during the VHO process.
[12]	Network prediction: Auto-regression RSS prediction with hysteresis for a mobile station.	Router solicitation for proxy (RtSolPr)	RSS	The enhanced procedure avoids unnecessary handover influenced by the ping-pong effect and maximizes the quality of transmission.
[13]	Network prediction: Proposed a new mobility based prediction algorithm with dynamic LGD triggering.	LGD	RSS	Minimize the latency time in the VHO process.
[8]	Network prediction: Presented a new algorithm for trigger generation and trigger prediction.	LGD, LD, LCU, LU	WiFi: RSS WiMax: Carrier to interference-plus-noi se ratio	Enable seamless handovers, and minimize service interruption.
[14]	Network prediction: Proposed a cross-layer scheduling prediction scheme to exploit LGD information from MIH.	LGD	RSS	Increase the effective range of QoS-sensitive services at the cell border while executing the handover Procedure.
[15]	Network prediction: Proposed a new VHO scheme on the basis of the prediction of mobility of MN to perform VHO between WiMAX and WLAN networks.	Duplicate address detection message	RSS, direction of the MN and velocity	Reducing unnecessary messaging overhead for router discovery and VHO preparation.
[16]	Network prediction: Proposed a user mobility prediction algorithm, which considers the coverage of varies types of BSs and varied mobility of vehicles, mass transportation, and pedestrians.	Probability that a MN will move into or out of the coverage of a BS	Bandwidth	Can effectively manage the bandwidth reservation or assignment among different BSs, and with the increasing of the new connections.
[17]	Network prediction: Proposed an intelligent model for generating MIH LGD trigger reliably	LGD	Time delay neural network	Increasing prediction accuracy and time gain.

perform an imminent handover. An HHO can serve as a sufficient parameter for the measurement of handover prediction. The metric alone cannot be considered as a reliable trigger in VHO because of several reasons:

1) The RSS varies significantly among different networks because of differences in coverage and techniques that are employed at the physical layers, which makes them difficult to be compared with Ref. [8]. RSS fading patterns can also be different among networks because of large differences in base station (BS)–MN distances.

2) RSS measurements can be a good indicator of link quality. More robust and proactive metrics (available bandwidth (ABW), service type) are needed to represent the quality and availability of the services because of the diverse features and services of these types of networks.

Therefore, a more robust and proactive metric not only indicates the availability status of network coverage but also predicts the duration of the coverage and availability of the network services. The above requirement is important in the handover initiation process during VHO because this requirement allows the MN to decide on matters regarding resource allocation and QoS management at an early stage.

Many researchers have been focused on the employment of these intelligent mechanisms to solve the NS problem. However, the use of these mechanisms in generating event services in the VHO prediction process to avoid unnecessary handover has not been sufficiently examined. Most researchers consider the LGD event as the predictive factor of link degradation. Many methods for generating LGD triggers are proposed. We have found that the 802.21 events, namely, link up (LU), link down (LD), and link coming up (LCU), can predict the ability of these mechanisms to adapt efficiently to the behavior of the VHO operation according to the context information. The LU event gives the indication that the detected technology is able to offer more bandwidth and RSS in negotiating with the new candidate’s base station, whereas the LD event gives the indication to stay in the current connection. The LGU event also predicts that it is possible to negotiate with the new candidate’s base station when it is the current link or when it is better than the current link.

4.2 Heterogeneous wireless networks selection

Selecting the network is generally a continuous process of choosing the most suitable network for a certain user to execute a certain operation. This selection process is based on a number of criteria like monetary cost, ABW, required QoS (delay and jitter), power consumption, and user preferences. The selection process needs an efficient, intelligent mechanism to solve the problems that the system might encounter[18]. The NS problem is considered to be complex because different access technologies often provide a variety of QoS supports and billing schemes. Conflicting parameters and criteria are sometimes involved in the process. Therefore, the NS problem involves a decision-making process that abides by multiple criteria. This section summarizes the recent works on VHO selection mechanisms in HWNs. Group decision making promotes many intelligent methods that are used in the selection of HWNs because of its broad applicability. Most existing theories and methods can be categorized according to the following classifications.

4.2.1 MADAM-based network selection solutions

Problems in multiple attribute decision making (MADM) involve the ranking or evaluating of a finite number of alternatives with multiple, and often conflicting, attributes. MADM methods are considered as the most famous and widely employed solutions to NS problems. WANG et al [19] have been regarded as the first to address the problem of NS in HWNs and identify a policy-enabled NS function where the cost is defined as a function of price, power consumption, and bandwidth. The function of these parameters is represented by the summation of their weighted, normalized form. The chosen network is usually the cheapest. Sorting out this cost function through the simple additive weighted (SAW) method is possible. A number of studies dating back from 1999 have offered several different viewpoints on the SAW method. Different functions of normalization, such as logarithmic, exponential, and linear piecewise functions, have been utilized to express various features of different elements into a numerical illustration. Several MADM methods have been proposed to address the NS problem. The most popular of these methods are TOPSIS (technique for order preference by similarity to ideal solution) [20], GRA (grey relational analysis) and AHP (analytic hierarchy process) [21]. MEW (multiplicative exponent weighting) has also been used as a scoring method for where the scores of the networks are calculated by the weighted product of the attributes [20]. The researchers who have used these MADM methods are summarized in Table 2.

4.2.2 Fuzzy based network selection solutions

The aim of the fuzzy logic (FL) method for VHO selection is to convert physical measurement into fuzzy concepts (analogous human thoughts) and retranslate them in quantifiable categories. Fuzzy logic is envisioned as a theory for handling uncertainties on complex systems and as an estimation hypothesis. The aim of using the FL in the VHO process is to develop computerized methods that employ reasoning and problem solving in selecting the best networks. These computerized methods would rely on human intelligence in selecting the best networks if reasoning and problem solving are not possible. Existing fuzzy-based VHO solutions that deal with the VHO handover decision are available. The basic framework of the FL selection method is listed in Table 3.

An FL-based NS scheme is presented to maintain the QoS of mobile users in the heterogeneous wireless environments. A group of FL rules in the form of linguistic IF-THEN has to be defined for the NS process. The user-and network-side attributes are placed into the fuzzy logic controller to carry out the FL rules to obtain the final decision results, which are usually called as the fitness ranking. The network with the highest fitness ranking is selected by the user. However, the rules for NS have to be manually configured by the user prior to NS, and the network complexity becomes alarmingly high as the number of attributes increases. Thus, the scalability of the FL-based schemes is extremely low, which limits their usage in the HWNs due to the super diversity of the networks.

4.2.3 Game theory-based network selection solutions

Game theory has been widely utilized in modeling strategic interactions among rational agents. Game theory is a part of mathematics that presents analytical tools that investigate the interactions between different, conflicting sides [32]. These game types have different categorizations. Game theory may be classified into two branches, namely non-cooperative and cooperative. Non-cooperative game theory studies the strategic selections arising from interactions between competing players, where each player independently selects his or her strategy to develop its utility or to decrease its costs. Nash equilibrium is the most popular solution for NS in the non-cooperative game theory [33]. Cooperative game theory presents analytical tools to examine the behavior of rational players as they work collaboratively. An important development that utilizes game theory for analyzing communication networks has been identified in research activities. Other classifications according to player types such as users versus users, users versus networks, and networks versus networks, are included in this theory.

Table 2 Proposed MADM selection methods in HWNs

Method	Author	Objective	Parameter	Advantage	Disadvantage
SAW	TAWIL et al [22]	Network selection: Proposed the distributed vertical handover decision scheme integrated with IEEE802.21 MIH to select the best network	Cost, bandwidth	Enhance the VHO decision by exchanging messages offered by the MIHF among the MN and networks	The proposed solution does not provide unique network characteristics, which makes the evaluation of the quality of networks hard to achieve and increases the performance evaluation needed
SAW& MEW	SAVITHA and CHANDRASEKAR [23]	Network selection: SAW and MEW methods are employed to select the best network	Cost, bandwidth, delay, jitter	Reduce the processing delay, and a trusted VHO selection is done in HWNs.	No specific method to generate the weight of each parameter
SAW& TOPSIS	SAVITHA and CHANDRASEKAR [4]	Network selection: Compared SAW and TOPSIS to find the best selection method	Cost, bandwidth, delay, jitter	Reduce the processing VHO delay	No specific method to generate the weight of each parameter
TOPSIS	SAVITHA and CHANDRASEKAR [24]	Network selection: Using the TOPSIS method to choose the best network	Cost, bandwidth, delay, jitter	Reduce the processing VHO delay	No specific method to generate the weight of each parameter
	SMAOUI et al [25]	Network selection: Selected the best suitable network interface for each application	Bandwidth, velocity support, load factor, RSS, and power consumption cost	Analyzed and validated the TOPSIS algorithm by applying it in varies scenarios with varies QoS profiles	Integrating many network parameters increased the complexity level in the Algorithm
GRA	SAVITHA and CHANDRASEKAR [26]	Network selection: Used the GRA method to choose the best network	Cost, bandwidth, delay, jitter	Reduce the processing VHO delay	No specific method to generate the weight of each parameter
SAW, MEW, TOPSIS and GRA	WANG and BINET [27]	Network selection: Proposed a four-step NS integrated strategy	Cost, power consumption, bandwidth, security level, traffic load, RSS, BER, jitter	Identify important issues like the usage of VHO properties, the tradeoff for handover to the new best network, the requirement of the efficient weighting method and the immoderate load balancing compromising importance of other criteria	Lack of study on how to solve these issues in the scope of MADM-based network selection

Table 3 Proposed fuzzy logic selection method in HWNs

Author	Objective	Parameter	Advantage	Disadvantage
LIAO et al [28]	Network selection: Provides a generalized VHO selection algorithm based on the FL theory	Power levels, cost, unused Bandwidth	Achieve optimization in the VHO decision process. The FL algorithm can carry out easily through the software method or through dedicated FL processing modules.	The form of FL membership functions must be modified to achieve better approximation
TU et al [29]	Network selection: Introduced FL decision algorithm to achieve VHO between WiMAX and WiFi based on the MIH scheme	RSS available bandwidth and the distance from access point	Integration of WiMAX and WiFi in HWNs environment based on MIH mechanism	The program is designed for the handover decision of a single network. Further study is required to apply the integration of multi-network environments
WILSON et al [30]	Network selection: Proposed FL selection strategy in refining the optimal choice of different wireless networks	SNR, data rates	Initial development has demonstrated that many conflicting inputs could be dealt with inference knowledge	More complexity is added, such as including different types of metrics and the rules may become overly complex
VASU et al [31]	Network selection: Proposed QoS-aware fuzzy rule based VHO mechanism that makes a multi criteria based decision	Available bandwidth, end-to-end delay, jitter, and BER	Proposed a new evaluation model by using a non-birth–death Markov chain, in which the states correspond to the available networks.	Connection lifetime is high and this lead to increases in end-to-end delay

The description of game theory components is needed to be identified in the network selection environment. Any game model must have three game parameters, which are players, strategies, and payoffs. Any model that does not have these three components is not considered as a game model. The users and/or the networks are the players in the game. Players that are seeking payoff maximization can select between varies strategies, like low monetary cost, higher bandwidth, and QoS. The payoffs can be estimated by using utility or characteristic functions that are based on different decision criteria, such as energy consumption, monetary cost, available bandwidth, network load, delay, jitter, and packet loss. The games can be formulated in such a way that they can target multiple objectives such as maximizing or minimizing varies resources, including cost, power, and bandwidth. Table 4 illustrates the components of game theory in the NS environment.

Table 4 Description of game components in NS environment

Game component	NS environment
Player	Networks and/or users who are playing the game
Strategy	A plan of reactions taken by the player throughout the game must consider the user's preference. This preference is represented by the weight in each parameter (cost, available bandwidth, delay, and packet loss) offered by the players
Payoff	Motivation of players represented by profit and estimated by using utility functions and scoring models, which are based on different parameters like cost, bandwidth, delay, packet loss, jitter, and power consumption

For selection purposes, game theory concepts have been used in HWNs to solve the NS problem. The NS problem is considered complex. Different game theoretical methods are modeled and aimed to solve the NS problem. Figure 6 shows the division of the available approaches into three main types, which are in accordance with the type of game and interaction between players, cooperative (users versus users [34], networks versus users [35−36], networks versus networks [37−39]), and non-cooperative (users versus users [40−41], networks versus users [42−46] and networks versus networks [47−51]). As seen from Fig. 6, most related literature considers the NS problem as non-cooperative games. Little of the cited works is focused on cooperative game, which relies on cooperation between networks.

The approaches presented in literature vary with regard to the following: game model (Prisoners Dilemma, Auction, Bayesian, Bargain, Trading Market, Multi-Leader Follower, Bankruptcy, Stackelberg, Coalition, Repeated, and Congestion) games, players (networks and/or users), strategies (transmission rates, available access networks, users satisfaction, type of applications, service requests, QoS, and so on), selection parameters (monetary cost, power consumption, available bandwidth, delay, packet loss, throughput, jitter, service type, and so on), and used wireless access technologies (IEEE standards and cellular networks). Tables 5 and 6 illustrate the comparison between the proposed game theoretical solutions.

The game theory methods are used to solve these contradicting situations. Thus, game models are logically used to investigate real conflicts and negotiation processes in the VHO decision. However, the game theory approach is not widely used in practical research because of a number of reasons. The most important reason is the absence of the common principle of optimal behavior in game theory. This absence means that the rational agreement from the point of view of one principle of optimality may not be the same from the point of view of the other.

4.2.4 Utility theory-based network selection solutions

In the NS mechanisms, all candidate networks are associated with a utility function. The chosen network is the one that presents the greatest utility value obtained from a weighted sum of the effective selection parameters. The network that maximizes the overall sum of permitted

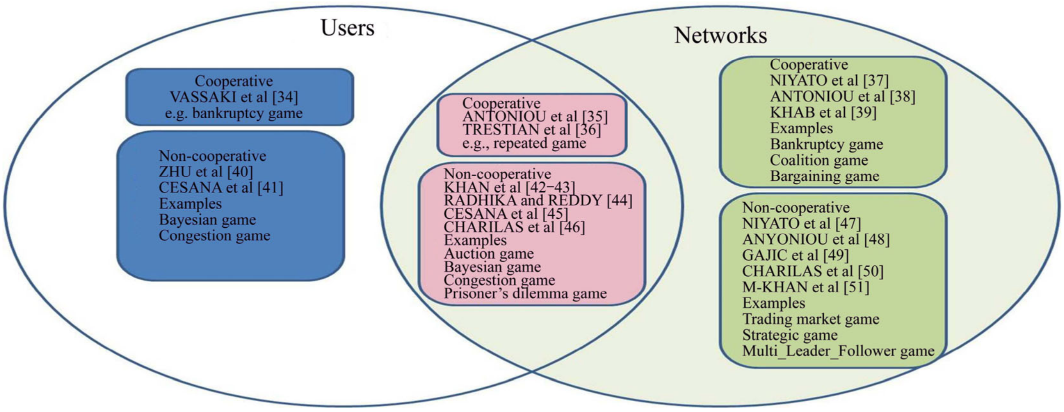

Fig. 6 Game-theory-related works

Table 5 Comparison between proposed cooperative game theoretic solutions

Author	Player	Model	Objective	Strategy	Payoff	Parameter
VASSAKI et al [34]	Users vs Users	Bankruptcy game	Optimal bandwidth allocation	Necessary bandwidth	Utility function	Available bandwidth, path gain, transmitted power and noise spectral density
ANTONIOU et al [35]	Users vs Networks	Repeated game	Compute a cooperative solution to select the best network that satisfies both user and network.	Network: tit-for-tat or cheat-and-return; User: Grim, Cheat-and-Leave, Leave and-Return, or Adaptive return	Utility function	Perceived quality (RSS and signal alteration rate), compensation received (price)
TRESTIAN et al [36]		Repeated game	Strengthen the cooperation between users and networks	For both network and user: Cooperate, Grim, Defect	Utility function	Energy consumption, quality utility, monetary cost
NIYATO and HOSSAIN [37]	Networks Vs Networks	Bankruptcy game	Bandwidth allocation: Allocate bandwidth from each network in a fair manner; Admission control: Guarantee the total transmission rate requested by the new connection.	Coalition form	Characteristic function	Available bandwidth
ANTONIOU et al [38]		Coalition game	Resource allocation: Networks aiming at participating in a coalition and at yielding the largest possible benefit to it	Coalitions	Characteristic function	Available bandwidth
KHAN et al [39]		Bargaining game	Resource allocation: Sharing bandwidth between different networks in a fair manner.	Offered bandwidth	Utility function	Available bandwidth

flows and satisfies the user demands is definitely the best network for a user to choose. This approach must take care of the user satisfaction. In general, the utility function is a solution that utilizes the scoring method to quantify the quality level, quality utility and utility value of candidate networks. Utility represents as a tool to measure the degree of user satisfactions [52]. The utility quality levels can be estimated from the collection of the information related to user preferences. The acceptable quality level is that a user may prefer to choose an access network that satisfy their needs, while unacceptable quality levels when the candidate network does not satisfy the user's need. The researchers on the use of utility theory in NS process are listed in Table 7.

The selection of utility function is another challenge which can present the user stratification quality levels and the overall quality utility value of each player (payoff). The player that has the highest quality value will be the most preferable to the user. Utility functions are provided to designate the player's awareness of performance and user fulfillment. The shape of the utility function of a user is related to the user's priorities for higher bandwidth, cost savings and better QoS. Due to the traffic heterogeneity which comes up with a huge number of various applications with various needs, accurate account of a utility function becomes very complicated. A number of related works try to elevate the network performance through exploiting a suitable shape of utility function. An example of the most well-known utility function shapes is illustrated in Fig. 7 [57].

For real time applications, a sigmoid function was introduced by the authors in Ref. [5] to formulate the user satisfaction behavior (Eq. (1)) and throughput parameter is considered as an important factor to measure the satisfaction levels as shown in Fig. 8.

$$u_{\mathrm{q}}(t_{\mathrm{h}})=1-\mathrm{e}^{\frac{\alpha t_{\mathrm{h}}^{2}}{\beta+t_{\mathrm{h}}}} \tag{1}$$

4.2.5 Combining multiple methods for network selection

The analysis of conflicting situations and negotiation processes have excited the common interest and become the subject of scientific investigations for communication. Taking into consideration certain limitations of mathematical models and the difficulty of verifying actual adequacy. The integration of different mathematical theories (MADM, fuzzy logic, game theory and utility theory) can get performance for analysis of conflicting situations in heterogeneous wireless network selection. Every method has its own strengths and weaknesses as listed in Table 8. The combination between different methods in order to develop advanced decision algorithms may add better performance to the system.

Table 6 Comparison between proposed non-cooperative game theoretic solutions

Author	Player	Model	Objective	Strategy	Payoff	Parameter
ZHU et al [40]	Users vs Users	Bayesian game	Network selection: Connect to the best available network	Probability distribution over actions according to the Bayesian strategy and the minimum bandwidth requirement	Utility function	Price and bandwidth
CESANA et al [41]	Users vs Networks	Congestion game	Network selection: Choose the network that minimizes the selection cost	Available APs in the network	Cost function	Congestion of the AP (number of interferences)
KHAN et al [42−43]		Auction game	Network selection: Choose the network that satisfies the user demands	Requested bandwidth with associated attributes	Utility function	Required bandwidth, mean opinion score, delivery response time
RADHIKA and REDDY [44]		Bayesian evolutionary game	Network selection: Choose the best network	Bayesian strategy	Utility function	Bandwidth, packet delay, jitter, supported velocity, bit error rate
CESANA et al [45]		Congestion game	Network selection: Development of strategies to choose automatically the best available network Resource allocation: Manage the radio resources when various networks operated by various and potentially competing actors coexist	Users: maximization of perceived QoS Network: maximize the number of customers	Characteristic function	Frequency allocation, number of customers per network and average interferers per user
CHARILAS and PANAGOPOULOS [46]		Prisoner's dilemma	Resource management: Admission and load control	Network: admit or reject. User: stay or leave	Utility function	Cost, delay, jitter, throughput and packet loss
NIYATO and HOSSAIN [47]	Networks vs Networks	Trading market game	Resource allocation: Allocate bandwidth to the service areas from the various access networks in a fair manner. Admission control-limit the number of ongoing connections	Amount of bandwidth offered	Utility function	Offering bandwidth, number of ongoing connections
ANTONIOU and PITSILLIDES [48]		Strategic game	Network selection: Choose the best network to satisfy a service request	Service requests	Utility function	Delay, jitter, and packet loss
GAJIC et al [49]		Two Stage multi-leader-follower game	User-provider association and resource allocation in HWNs setting	Offered prices	Utility function	The willingness to pay, the amount of allocated time
CHARILAS et al [50]		Non-Zero-sum	Admission control: Distributes fair service requests between two wireless networks	Service requests	Utility function	Network efficiency and network congestion
KHAN et al [51]		Strategic game	Network selection: Choose the best access network	Service requests	Utility function	Service type, signal strength, user preferences, speed of the user and battery level

Table 7 Proposed utility theory selection methods in HWNs

Author	Objective	Utility form	Parameter	Advantage	Disadvantage
NGUYEN-VUONG et al [52]	Network selection: Define an appropriate decision mechanism in the frame of the NS	Sigmoid function	Bandwidth, Cost	Take into account the behaviors of the MNs	Facing difficulty to formulate multi-criteria utility function
NGUYEN-VUONG et al [53]	Network selection: Proposed automatic network selection mechanism to select the best access network,	Sigmoid function	Link quality, cost, Battery lifetime, velocity and network load	Users are able to express their preferences in terms of level of importance	Difficult to calculate the user preference weight for every application
CHAN et al [54]	Network selection: Choose the most efficient network Resource allocation: Allocation controls of the network resources	Voice: step function; Video and data: Sigmoid function	RSS versus Price	Balance traffic load between various networks and effectively avoids network congestion	In HWNS for selection purposes other parameter must be considered (Bw, cost, QoS)
ORMOND et al [55−56]	Network selection: Intelligent network selection decision strategies to aid them in their choice	Piece-wise linear function	Required transfer completion time	Initial development has shown that many conflicting inputs can be dealt with inference knowledge	The NS strategy was used just for non real-time data transfer while in HWNs it needs to be used for real-time data transfer

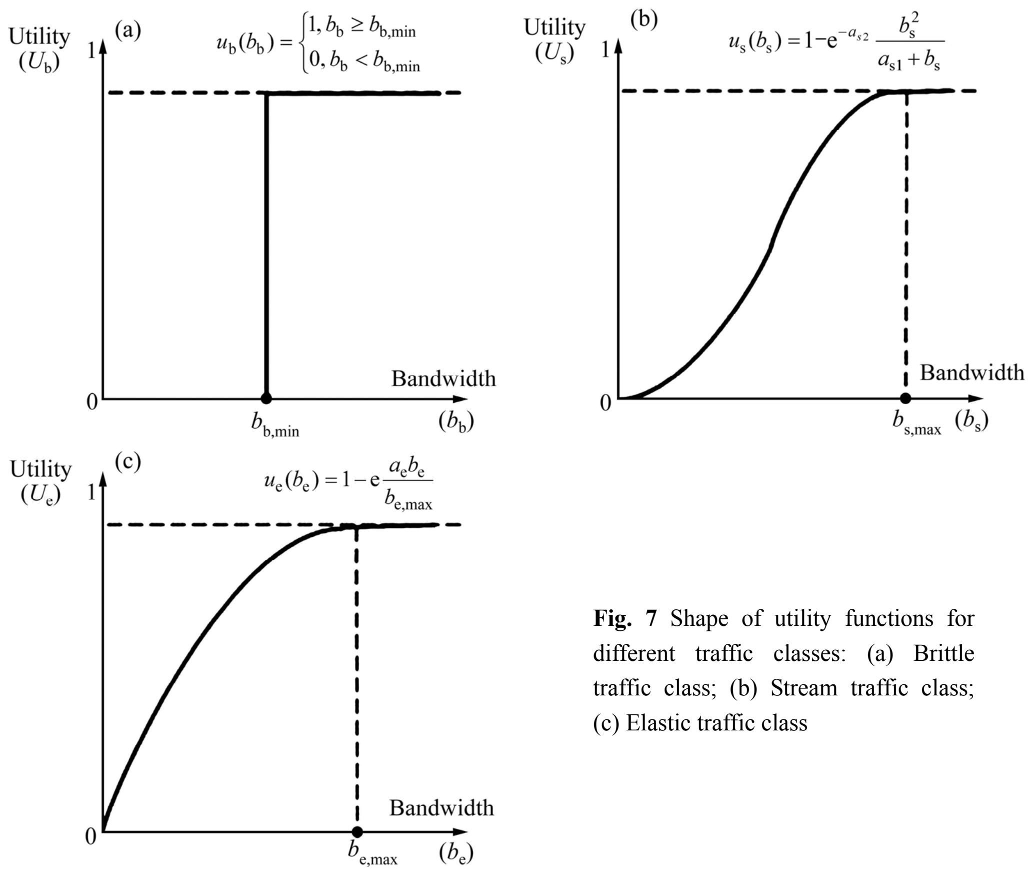

Fig. 7 Shape of utility functions for different traffic classes: (a) Brittle traffic class; (b) Stream traffic class; (c) Elastic traffic class

Generally, in the previous works in FL concept is applied to select when and to which network handover should be performed between different candidate access networks. These are combined with the multiple criteria or attribute concept in order to develop advanced decision algorithms for both real-time and non-real-time applications. It is pointed out that classical MADM methods cannot efficiently handle a decision problem with imprecise data that decision criteria could contain. Therefore, the use of FL is not only to deal with imprecise information but also to combine and evaluate multiple criteria simultaneously. Hence, FL concept provides a robust mathematical framework in which VHO decision can be formulated as a fuzzy MADM [58].

The multi-criteria utility theory is used with AHP to solve the problem of NS. AHP method is a strategy for multiple criteria decision making and has been widely

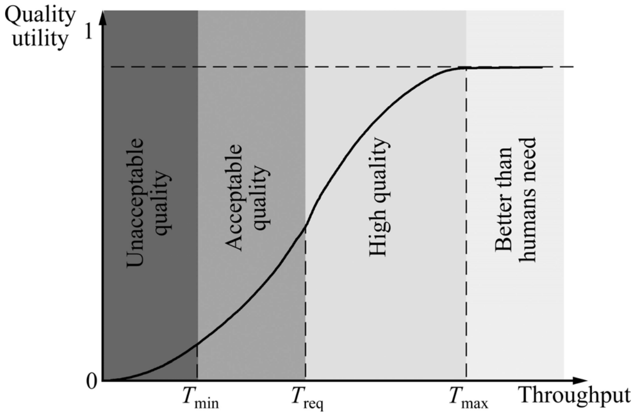

Fig. 8 Sigmoid utility function in real time applications [5]

applied with utility theory to solve the problem of NS [49]. The combination of these methods can identify the weight and quality levels for scoring methods [59].

The present work based on the literature takes into consideration the pros and cons of combination of multiple methods (MADM, fuzzy logic, game theory and utility theory) to model the NS problem and find the best solution. The researchers on the use of multiple decision methods to solve the NS problem are summarized in Table 9.

5 Proposed architecture for best network selection

Our proposed method is aimed at finding a new NS method to identify the next generation wireless networks environment. Our method seeks to select the best network in HWNs environments. This proposed method is newly established for the purpose of integrating a new selection mechanism control in the HWNs environment. The interaction game between different networks in a non-cooperative manner maximizes their payoffs and satisfies user preferences. The new method is based on the integration of one of the MADM scoring methods, such as SAW or MEW, in the framework of the non-cooperative game model. The new model includes three steps. First, we use SAW or MEW as a scoring method to find the winner of the competition. Second, the non-cooperative competing game is employed to determine the strategy of the user and their reaction from the players (networks strategies). Third, the payoffs are calculated for the networks based on relative weights. Additionally, a utility function is evaluated for all networks. We consider the NS problem as a non-cooperative competing game model. In this model, the players are the networks, the strategies are the reaction of players taken for consideration, the user preference is the weight of the parameters, and the payoff depends on the ability of each network to satisfy the user requirement.

We consider the competition between different candidate networks. These networks are operated independently, aiming to provide their services to users. In making a decision, the user may either stay in the present network connection or move to another available network connection providing better service. At any given time, a user wants to receive a better service, the final decision is preceded by the expression of the users' preferences and needs for various criteria parameters. NS is divided into two steps, namely, reliance on certain network information that best satisfies user preference and processing of user preference data. When one of the aforementioned events occurs, the game selection model is executed to find the best network that provides newly required service before the handover execution process. The game is non-cooperative because the supposition that each network utilizes a strategy is plausible. Additionally, each network maximizes their own payoff, irrespective of the payoff of other networks. In the game selection model, normalization of the attribute is necessary to obtain comparable scales. Normalization, in which all criteria are measured in dimensionless units, offers the advantage of facilitating inter-attribute comparisons. The contribution of the game selection model is to create new NS policy user control that can adapt to various wireless networks based on the priority of the user and their satisfaction.

Selecting a suitable utility function to model human user preferences under the doubt of the radio environment is challenging. A realistic group of suppositions and conditions assisted in deciding on the possible shapes and threshold values for the utility function. For the purpose of modeling user satisfaction in the game model, a system is proposed. Additionally, quality utility U_q is defined as a function of throughput.

Table 8 Comparison between different mathematical methods for in VHO selection

Method	Objective	Decision speed	Negotiation	Implementation complexity	Accuracy	User-centric	Efficiency
MADM	Combination of multiple attributes	Fast	No	Simple	High	Yes	High
Game theory	Equilibrium management between multiple entities	Middle	Yes	Complex	High	No	High
Utility theory	Utility evaluation	Fast	No	Simple	Middle	Yes	Medium
FL	Imprecision and ling	Fast	No	Simple	Middle	Yes	Medium

Table 9 Proposed selection methods that combine different mathematical methods in HWNs

Author	Method	Objective	Parameter	Advantage	Disadvantage
RAMIREZ et al [60]	FL, AHP	Network selection: Select the network that offers the best QoS for the MN applications.	Bandwidth, delay, Price, Jitter and PER	Performs handover to the best QoS network providing	Facing difficulty to formulate multi-criteria utility function
YANG [61]	FL AHP SAW MEW	Network selection: Proposed NS algorithm with QoS provision across WLAN and WMAN.	RSS , price, bandwidth, delay, PER and jitter	Provides high data rate and enhanced multimedia services	The proposed solution is supported just for VHO between WiMAX and WiFi
OLIVEIRA et al [62]	FL, SAW, TOPSIS	Network selection: Purposed NS mechanism that considers the imprecise and dynamic nature of the access networks	Latency, link stability and throughput	Can deal with uncertain network parameters by considering a heterogeneous wireless scenario	Some parameters are difficult to measure or identified
KASSAR et al [63]	FL and AHP	Network selection: Network selection between UMTS-WLAN based on the context-awareness concept	User side: User preferences, service capabilities, network interfaces and battery status Network side: bandwidth, cost , delay, jitter, RSS, PER and packet loss	The proposed NS process can provide flexibility and efficiency	Used many parameters in both network and user side without justification why he used these parameters
Chamod-rakas and MATAKOS [64]	FL, TOPSIS utility function	Network selection: Choose the optimal network that achieves the best balance between performance and energy consumption	Bandwidth delay, energy consumption	Takes into account user preferences, QoS, network conditions, and energy consumption requirements	No mention which method based on to generate the weight criteria
CHANG et al [65]	Utility & non-cooperative Strategic Game	Network selection: Compute the preference value from the network point of view, seeking to decrease the number of handovers and achieve load balancing.	Network load, call holding time, the dwell time and mobility	Has good QoS satisfaction, allows the system to accommodate more calls than in the iterative TOPSIS scheme, reduce the handover occurrence frequency	In this method the packet dropping rate in the real time call is higher than iterative TOPSIS
PERVAIZ and BIGHAM [66−67]	Strategic Game & AHP	Network selection: Choose the network that fulfills the user requirements.	Reputation, degradation, price and availability	Provide a service prioritization and user priority	No decision whether the networks must compete for a particular user or not in the overload or emergency scenarios
FEI et al [68]	Utility & AHP	Resource allocation: Proposed a dynamic bandwidth allocation scheme for multiple services in HWNs	Network: Network capacity and available capacity User: coverage of wireless networks and Service density	Guaranteeing both the fairness of the edge users and the network system performance	The proposed method needs to simplify the parameter setting and use new mathematical methods to optimize the block probability
TRESTIAN [69]	MEW & repeated cooperative game	Network selection: Select the best value candidate network that fulfills the user requirements, maintaining the user 'ABC' for multimedia streaming	Energy consumption, the quality of the multimedia stream, the monetary cost, and the user mobility	Achieve maximum power savings in a heterogeneous wireless environment while maintaining a certain level of user perceived quality	No specific method to generate the weight

We define a zone based on the service used. Utility functions are defined based on the service type, which describes the user satisfaction with quality levels for certain QoS parameters. The total score function that represents a mixture of multi-criteria utility functions are identified. The overall utility is defined by using a score function. For the voice service, the mathematical formulation of this quality utility function is provided in Eq. (2). Figure 9 explains the shape of voice service. Here, T is the throughput, and $T_{\min}$ is the minimum throughput.

$$U_{\mathrm{q}}(T)=\begin{cases}0, & T<T_{\min}\\ x, & T\geq T_{\min}\end{cases} \tag{2}$$

For video and VoIP services, the tanh function is the most suitable to represent the utility function. The quality tanh utility function is computed based on four quality levels. If the value of the throughput (T) is less than the minimum throughput ($T_{\min}$), then the quality is considered unacceptable. By contrast, values higher than

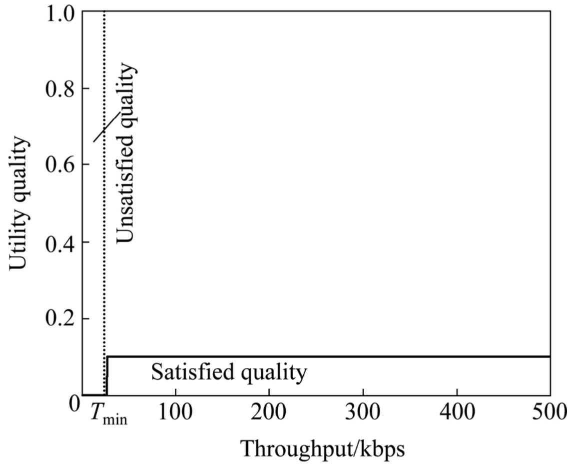

Fig. 9 Quality utility function for voice service

the threshold (T_{min}) consider the quality acceptable. To guarantee the representation of measurements of high quality levels for video and VoIP services, the required threshold throughput (T_{req}) is identified and utilized as an indicator of the high quality level. This requirement is that the (T) imposed should be higher than (T_{req}). The values above the maximum throughput (T_{max}) threshold are considered better than human needs. The mathematical formulation of this quality utility function is provided in Eq. (3). Figure 10 explains the shape of VoIP and video services.

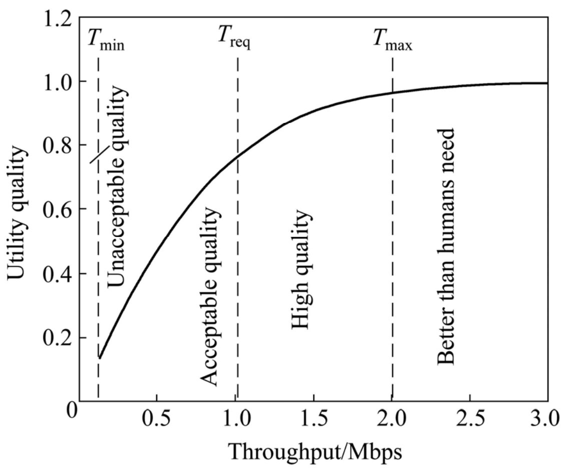

Fig. 10 Quality utility functions for video and VoIP services

$$U_q(T)=\begin{cases}0,\ T<T_{min}\\ \tanh(T),\ T\geq T_{min}\end{cases} \quad (3)$$

Data service can be represented as quality sigmoid utility function. The mathematical formulation (sigmoid function) of this quality utility function is provided as

$$U_q(T)=1-e^{-\varepsilon T} \quad (4)$$

where ε refers to positive parameter, regulating the shape of the sigmoid utility function. The value is ($0\leq\varepsilon\leq1$). The quality utilities of data service are divided into three quality levels (low, medium, and high). Figure 11 explains the shape of data service.

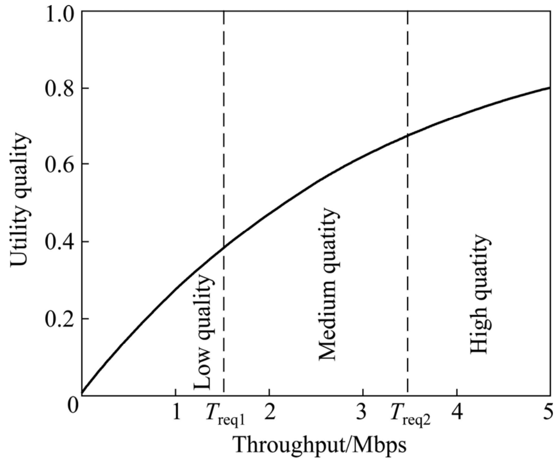

Fig. 11 Quality utility function for data service

6 Conclusions

The review provides a comparison and analysis of the different state-of-the-art theoretical solutions on network prediction and selection concepts as well as outlines the problems faced by the NGWNs. The review also presents a comprehensive review of this topic. This work provides a useful categorization based on the theoretical methods used to solve these problems. We discuss different methods to solve network prediction and selection problems. Major findings from this research that the integration of more than one method can help solve the NS problem. Additionally, we propose a new idea, that is, to use one of the MADMs methods as a scoring method in the framework of the non-cooperative game computing model. We learn that using other parameters, such as bandwidth and service type, with RSS can be an effective way of avoiding unnecessary handover.

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