Network Selection in Wireless Heterogeneous Networks: a Survey

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Abstract—Heterogeneous wireless networks is a term referring to networks combining different radio access technologies with the aim of establishing the best connection possible. In this case, users with multi-mode terminals can connect via different wireless technologies, such as 802.16, 802.11, UMTS, HSPA and LTE, all at the same time. The problem consists in the selection of the most suitable from all radio access technologies available. The decision process is called network selection, and depends on several parameters, such as quality of service, mobility, cost, energy, battery life, etc. Several methods and approaches have been proposed in this context, with their objective being to offer the best QoS to the users, and/or to maximize re-usability of the networks. This paper represents a survey of the network selection methods used. Multiple attribute-dependent decision-making methods are presented. Furthermore, the game theory concept is illustrated, the use of the fuzzy logic is presented, and the utility functions defining the network selection process are discussed.

Keywords—always best connected, fuzzy logic, game theory, multiple attribute decision making, quality of service, radio access technologies.

1. Introduction

Two decades ago, the IEEE dominated the Internet market with the IEEE 802.11 standard. It was a big innovation in terms of cost and high data throughputs. At that time, 3GPP's cellular technology was the Global System of Mobile Telecommunication (GSM). It is considered to be an excellent technology for calling and sending text messages, but it can't provide Internet access. This has pushed 3GPP developers to introduce the Global Packet Radio Service (GPRS). Unfortunately, Internet access with a higher data throughput was not possible either. In the next update, 3GPP changed the circuit-switched functionality to the packet-switched variety, and they called this release the Universal Mobile Telecommunications System (UMTS) or the third generation network (3G).

Before 3G networks arrived, radio access networks were mainly homogeneous. Later, development of network technologies has led to an impressive growth of Internet applications and services, as well as to the development of the mobile user industry. Presently, people are equipped with smartphones and seek "always the best connectivity"

(ABC). It is obvious that no single Radio Access Technology (RAT) can offer the ABC. Therefore, it was necessary to move from homogeneous systems to their heterogeneous counterparts. The aim of the fourth generation (4G) networks is to satisfy the ABC concept by offering mobile users the ability to take advantage of those networks which offer different architectures and performance levels. Nowadays, we have a variety of RATs: WLAN, IEEE 802.11, UMTS, HSPA and LTE. All of them make up a heterogeneous environment (Fig. 1). A heterogeneous system allows mobile users to choose multiple RATs based on several criteria. This choice is known as network selection (NS) and is the very area this paper is concerned with.
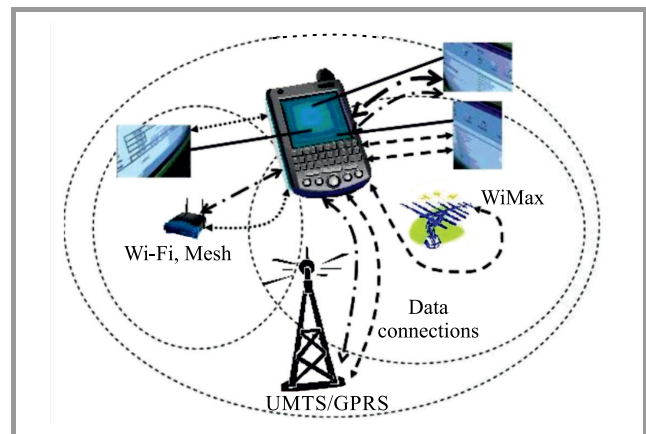
Fig. 1. Heterogeneous wireless environment.

The network selection procedure consists of selecting the best network from all those that are available. However, due to many parameters, such as cost, QoS and the amount of energy consumed, the decision is complex. This allows us to say that the NS problem may be defined, in basic terms, as a dynamic and automatic choice of the best wireless access network, taking into account a number of parameters. In the case of older cellular technologies, NS was based on physical layer parameters, and the mobile terminal was often assigned to the best received base station. Such a selection policy is obviously not suitable for heterogeneous wireless access technologies, because the user may favor to connect to a RAT with a lower load, located at a greater

distance and offering a lower level of the received signal strength (RSS), rather than to a more loaded cell with high RSS.

NS in a heterogeneous environment can be described as a multiple attribute decision making (MADM) problem, because of the number of parameters and criteria involved [1]–[4]. Other methods, such as fuzzy logic, game theory and utility functions have been proposed to solve the NS problem in [5], [6] and will be surveyed in this paper. Other methods pertaining to multi-criteria optimization have been used to deal with the NS problem as well. These include artificial intelligence, neural networks and genetic algorithms, and will not be in this paper because of their limited popularity.

This paper is organized as follows. After introduction, Section 2 is devoted to the NS procedure, while in Section 3 we focus on the approaches and methods used to solve the NS problem, as presented in literature. In Section 4, a summary of the discussed methods and approaches is presented, along with a recap table.

2. Network Selection Process

The NS process consists of switching between different RATs, to be always best served. So, when a multi-mode user discovers the existence of various RATs within its area, it should be able to select the best network in terms of delay, jitter, throughput and packet loss rate (Fig. 2). The NS procedure is the general case of the handover process (HO), which can be either centralized (network-centric) or decentralized (user-centric).

For the network-centric approach, the operator controls the whole process and makes decisions. It is a good strategy to avoid problems, such as selfish behavior of users who try to get the best RAT at the same time, which results in congestion. On the other hand, this strategy cannot be used in the case of multiple operators. For the user-centric approach, users make decisions by themselves. This approach is known as decentralized and can easily generate congestion because of the selfish nature of users. Nowadays, almost all operators offer 3G and 4G radio access and also Wi-Fi connections, so the first approach is more suitable for regular use.

Many parameters influence the process of selecting the best RAT: battery level, energy required to get the services requested, RSS received, cost, bandwidth acquired, user preferences, QoS required, etc. These parameters can be categorized into four groups:

- network conditions parameters – information about network conditions, such as network load, coverage area, network connection time, available bandwidth,

- application requirements parameters – information about the threshold needed by the service application to be in the normal state, as well as required throughput, delay, jitter, packet loss rate, and energy needed for the application,

- user preference parameters – information relative to end users, i.e. user acceptable cost, preference between cost and service quality,

- mobile equipment parameters – information about the user's device, i.e. battery level status and mobility.

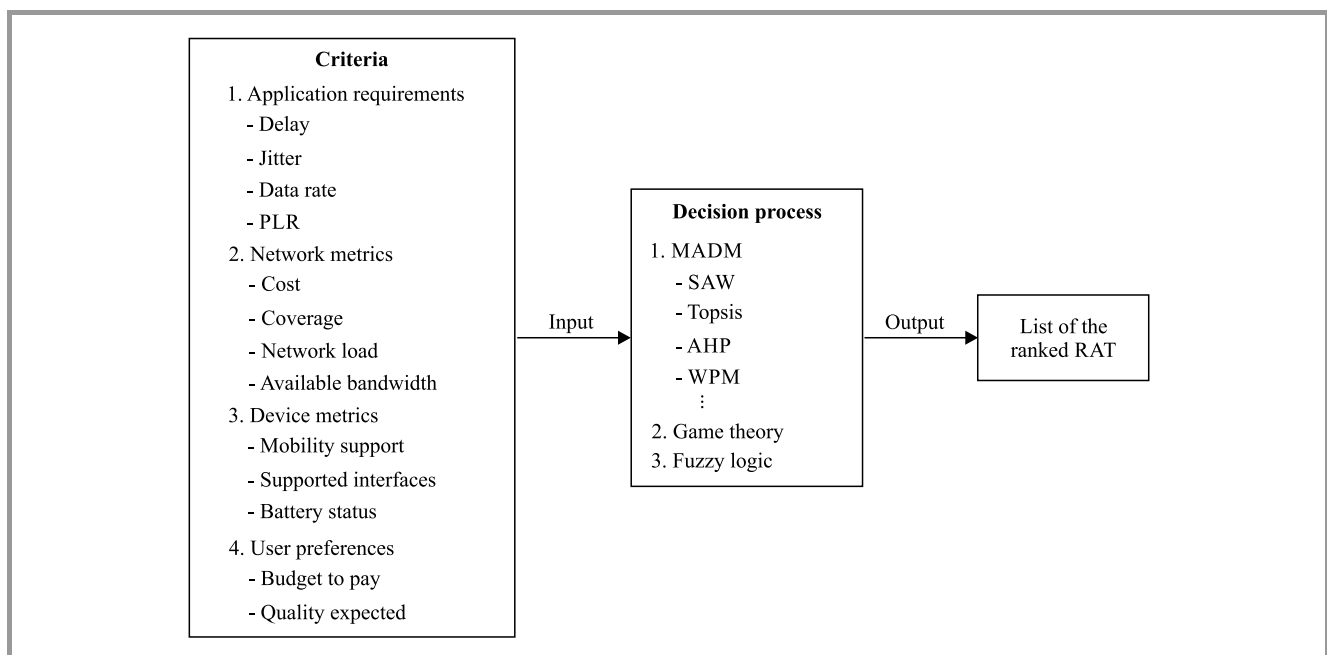The parameters may also be dynamic or static, and may require to be maximized or minimized. For example, the

Fig. 2. Network selection process.

Table 1
Network selection inputs and classification of parameters

Parameters group	Parameters	Type	Expected as
Network conditions	• network load	Dynamic	Minimized
	• network coverage	Static	Fixed
	• network connection time	Dynamic	Minimized
	• available bandwidth		Maximized
Application requirements	• throughput	Dynamic	Maximized
	• delay		
	• jitter		
	• PLR		
	• energy consumption		
User preferences	• budget	Static	Fixed
	• cost		
Mobile equipment	• battery level	Dynamic	Fixed
	• mobility		

delay parameter is related to network conditions, network load and user's RSS – it is a dynamic parameter that must be minimized (Table 1).

The network selection process consists mainly of the following actions:

- Monitoring step. It consists in identifying the available RAT, collecting the network's radio parameters and other RAT characteristics. In this stage, some of the parameters are estimated and others are calculated.

- Decision step. It initiates the NS decision. The choice of the best network is based on the monitoring process and on other parameters provided by the mobile device, such as user's preferences. In this stage, the decision process is applied to rank the RATs.

- Execution step. It consists in connecting to the target RAT.

The NS procedure is started when a new service is requested, such as a video/VoIP call or a data transfer service, also when the received RSS drops below the threshold value and after the user's radio connection worsens, for instance when the user is mobile. As far as the application requirements are concerned, NS depends on the type of service desired. For VoIP, delay and packet loss rate are important parameters. For a video service – bandwidth and delay, while for a best effort service – the bandwidth acquired.

3. Network Selection Solutions

Many authors have modeled the solution of the NS problem, presenting different propositions in order to find the most appropriate one. In this section, we present a survey of the methods used to solve the NS problem.

3.1. MADM Methods

MADM is an analytical approach focusing on preferential decisions. It treats problems with numerous decision-related criteria, and is widely used in various areas of expertise, such as economy [7]–[9]. The basics of this approach are divided into three groups:

- Alternatives – a set of the actors who will be ranked. In the NS scenario, the alternatives have the form of RAT lists.

- Set of attributes – it represents the parameters or the criteria used in the decision-making process. For the NS scenario, the parameters are the throughput achieved, jitter, packet loss and delay.

- Weights – the importance of a given parameter or the criteria relied upon in the decision process.

By using such a taxonomy, we get a decision matrix representing the system, where the columns are the criteria and the lines are the alternatives.

Several decision-making methods have been proposed in MADM context, such as: simple additive weight (SAW), technique to order preference by similarity to ideal solution (TOPSIS), weighted product model (WPM) and analytical hierarchy process (AHP) [8].

SAW, TOPSIS and WPM are also qualified as ranking methods that need other methods to weigh the criteria, while AHP relies on a process that generates the weights for the criteria.

It is important to note that these methods are applicable only when all data of the input matrix are expressed with

the use of the same unit. Therefore, data must be normalized, which is an important step in the network selection procedure. Table 2 represents a non-exhaustive list of common normalization methods.

Table 2
Normalization methods

Method	Value
Max-min	$e_{ij} = \dfrac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})}$
Sum	$e_{ij} = \dfrac{x_{ij}}{\sum\limits_{i=1}^{n} x_{ij}}$
Square root	$e_{ij} = \dfrac{x_{ij}}{\sqrt{\sum\limits_{i=1}^{n} x_{ij}}}$

The weight that a given parameter has for the use is another important point, e.g. QoS-based, cost-based and/or energy-based. Weights are related to the user profile and can be subjective or objective. Subjective weights are empirical values based on experience. For example, in the case of QoS-based users, while initiating a VoIP session, such parameters as delay and packet loss ratio have 60 to 70% of importance and bandwidth is not as important. In the case of a video session, bandwidth is more important than other parameters (50% of importance). Objective weights are given by the formulas shown in Table 3.

Table 3
Weighting methods

Method	Value
Entropy	$w_j = 1 - \dfrac{1}{N} \sum\limits_{i=1}^{n} \left[x_{ij} \ln(x_{ij}) \right]$
Variance	$w_j = \dfrac{1}{N} \sum\limits_{i=1}^{n} x_{ij}$
Eigenvector	$w(B - \lambda I) = 0$

The AHP method contains an auto-creative system to generate the weight vector using the eigenvectors and eigenvalues of the input matrix.

3.1.1. Simple Additive Weight (SAW)

SAW is a method for the case of multiple-criteria systems [8], [10], [11]. In SAW, the first data is normalized, then the candidate having the highest/lowest value is selected:

$$R_{SAW} = \sum_{i=1}^{n} \left(w_j \times r_{ij} \right) , \qquad (1)$$

where R_{SAW} is the value of each candidate, w_j is the weight value of the parameter j and r_{ij} is the normalized value of parameter j and network i.

The SAW method has been widely used in the context of network selection. In [11] and [12], authors have used the SAW method to get a ranked list of networks, while in [8], authors made a mix between the game theory and the SAW method. When the NS problem is approached by using the SAW method and other variants, the main benefit of the SAW method resides in its simplicity and low complexity. However, its drawback is that one parameter can be outweighed by another one.

3.1.2. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS is an aggregating compensatory method based on the concept that the chosen solution should have the shortest geometric distance from the positive ideal solution [13] and the longest geometric distance from the negative ideal solution. The normalized data for each parameter are weighted and therefore the geometric distance between each alternative and the ideal alternative is computed. The TOPSIS process is carried out as follows.

- First, an evaluation matrix consisting of m alternatives and n criteria is created, with the intersection of each alternative and criterion given as x_{ij}. It results in a matrix $(x_{ij})_{m \times n}$.

- The matrix $(x_{ij})_{m \times n}$ is then normalized to get $(r_{ij})_{m \times n}$ using one of the methods from Table 2.

- Calculate the weighted normalized decision matrix where $t_{ij} = w_j \times (r_{ij})_{m \times n}$, $w_j = \frac{W_j}{\sum_{i=1}^{n}(W_j)}$, $\sum_{i=1}^{n}(W_j) = 1$ and $j = 1, \ldots, m$, $i = 1, \ldots, n$.

- Determine the best and worst alternative A_b and A_w, respectively.

$$A_b = b_j^P = \max(t_{ij}) , \; j \in J_+ ,$$

$$A_w = w_j^P = \min(t_{ij}) , \; j \in J_- ,$$

where J_+ and J_- contain the criteria with positive and negative impact respectively.

- Calculate the separation measure for each alternative:

$$D_P = \sqrt{\sum_{i=1}^{n} \left(w_j^2 \times (r_{ij} - b_j^P)^2 \right)} ,$$

$$D_N = \sqrt{\sum_{i=1}^{n} \left(w_j^2 \times (r_{ij} - a_j^N)^2 \right)} .$$

- Calculate the relative closeness to the ideal solution

$$R_{TOPSIS} = \frac{D_P}{D_P + D_N} . \qquad (2)$$

TOPSIS has been applied to the network selection problem in several works, e.g. [9], [11], [14]. In [11], authors compare the performance of vertical handover using SAW

and TOPSIS. They concluded that TOPSIS outperforms the SAW method. In general, TOPSIS and other compensatory methods managed to avoid the problem that a parameter can be outperformed by another one by allowing a trade-off between criteria. This means that a poor value of one criterion can be neglected by a good value in another. This offers a huge benefit and is more sensible than non-compensatory methods, which use a threshold system.

3.1.3. Weighted Product Model (WPM)

WPM, also known as multiplicative exponential weighting (MEW), is a method similar to SAW [15]. The difference consists in the replacement of the addition operation used in the SAW method, with multiplication. Each alternative decision is compared with the remaining ones by multiplying a number of ratios, one for each decision criterion. Each ratio is raised to the power equivalent to the relative weight of the corresponding criterion:

$$R_{WPM} = \prod_{i=1}^{n} (r_{ij})_j^w \ . \tag{3}$$

Authors in [16] made a comparison between SAW and WPM methods in the context of vertical handover. They used the relative standard deviation as a metric of comparison and they arrived at a conclusion that WPM is better than SAW. In [17], the WPM method was used in the context of heterogeneous systems. Their conclusion is that the WPM method is a more robust approach for dynamic decision making and it penalizes the attributes with poor quality.

3.1.4. Analytical Hierarchy Process (AHP) and Grey Relational Analysis (GRA)

AHP assumes that one complicated problem is decomposed into a multiple-hierarchy simple sub-problems. AHP steps are:

- decomposing the problem into a hierarchy of sub-problems, where the top node is the final goal and where alternatives are listed for each criterion,

- pair-wise comparison of attributes and translating them into numerical values from 1 to 9,

- calculating the weights of each level of the hierarchy,

- synthesizing weights and getting overall weights.

As far as the GRA method is concerned, it is used to rank the candidate networks and it involves the following steps:

- normalization of data is performed considering three situations: higher is better through lower is better, and nominal is the desired,

- definition of the ideal sequence in the three situations considered is set: the ideal sequence contains the higher bound, lower bound and moderate bound,

- computing the grey relational coefficient (GRC): the sequence in which GRC is larger is more favorable.

The AHP is usually coupled with the GRA method: AHP for weighting, and GRA for ranking alternatives. Authors in [18] used a modified version of AHP and compared it with normal AHP using the QoE criterion. Their numerical results show that the proposed scheme outperforms the conventional AHP scheme, resulting in a good load balance. In [19], authors relied on AHP to rank various criteria used to compare the desirability of different Internet advertising networks. The proposed model provides an objective and effective decision model to be used by advertisers in selecting an Internet advertising network.

To recapitulate: MADM methods are widely used to solve the network selection problem, this is due to the fact that network selection involves the same problems as are solved by MADM. Moreover, these methods are known for their ease of use, clarity and low complexity of computation. The disadvantages of these methods are listed below.

Firstly, these methods do not offer the same level of performance with respect to different services (VoIP, video calls and web browsing) (Table 4). Secondly, they suffer from the problem of ranking abnormality, i.e. the phenomenon occurs in the MADM methods when an exact replica or a copy of an alternative is introduced or eliminated.

Authors in [20] have shown that the rank reversal problem occurs in the majority of well-known MADM methods. This problem has been addressed in other works [21], [22], by introducing specific modifications, but the original versions of MADM methods suffer from the rank reversal problem. Additionally, the AHP method is very complicated and requires complex computations when calculating the vector of weights. Due to all these reasons, we can say that MADM are a good solution, but the lack of a general method that would be suitable for all kinds of services is a problem.

Table 4
MADM method pros and cons

Advantages	Disadvantages
Easy to understand	Rank reversal phenomena
Easy to implement	High complexity such as AHP
Good results in some cases	Good performance with some services and bad results for others

3.2. Game Theory

Game theory allows to model competitive situations, which implies an interaction between rational decision makers and mutual, and possibly conflicting interests [9], [11], [12]. It provides an analytical tool to predict the outcome of complicated interactions between rational conflicting entities.

In this paper, we focus on the use of game theory for modeling the network selection problem [23].

An example of a conflicting scenario in which a game theory solves the problem is described below. As a rule, the fundamental characteristic of a game is that the gain of a player depends on his choices and also on the choices made by the other players. Games of this type are known as strategic games.

A game is represented mainly by three sets: a set of players that contains the rational actor competing to get a bigger pay-off. A set of actions or strategies which depends on the information available in the system. Obviously, each player seeks the action which maximizes their revenue. The pay-off is the objective function representing the player's revenue when choosing a specific strategy. The pay-off for each player can be represented as the actual or expected benefit the player receives by playing the current strategy. The game is played until the player is capable of obtaining more gains. When the pay-off cannot be enhanced any further with any other strategy combinations, an equilibrium known as the Nash equilibrium is reached.

The Nash equilibrium occurs basically when no player can obtain more gain by changing their strategy, with the strategies of the other players remaining unchanged. The Nash equilibrium is a combination of the best strategies for all players. A detailed representation of a strategic game is:

- $Game = \{P, A, G\}$;

- $P = \{1, n\}$ the set of players;

- $A = \{a_1, a_n\}$ the set of actions, denoting the set of strategies available to the player i, $1 \le i \le n$;

- $G : \{payoff\}$ represents the reward achieved when choosing a strategy. Here, to simplify things, the pay-off function is a linear summation of local gains, with the weights of each parameter applied.

Different types of games are used to model various cooperative or competitive situations between rational decision makers. Some of the most widely used game theory models are outlined below.

3.2.1. Cooperative and Non-cooperative Games

A cooperative game is a situation in which players claim to display cooperative behaviors. In this situation, the players plan, in groups, to choose their actions. In a non-cooperative game, also known as a competitive game, all options available to the players are specified, while contracts underlying the coalitions in a cooperative game are not described. Each player tries to reach his goal without regarding the other players. Here, the players are called rational [24]. Generally, non-cooperative games admit a solution called the Nash equilibrium, while for the cooperative games the solution is a total surplus generated by the coalition of players.

3.2.2. Games with Complete/Perfect Information

Complete information is a term used in game theory to describe games in which knowledge about other players is available to all participants. Every player knows the pay-off and the strategies available to other players. Games with complete and perfect information are significantly different. In a game with complete information, the structure of the game and the pay-off functions of the players are commonly known, but players may not see all of the moves made by other players. For the perfect information games, each player is perfectly informed of all the events that have previously occurred, but may lack some information about the pay-off of others players or on the structure of the game. Inversely, in games with incomplete information, some players do not know the information of other participants, like other players' pay-off. In a game with imperfect information, players are simply unaware of the actions chosen by others. However, they know who the other players are, their possible strategies and their preferences. Hence, the data about the other players is imperfect, but complete [23], [24].

3.2.3. Repeated Games

In strategic games, players make their decisions simultaneously at the beginning of the game. On the contrary, the extensive game model defines the possible orders of events. In this case, players can make decisions during the game and they can react to others decisions. Extensive games can be finite or infinite. Repeated games are a variety of extensive games in which a game is played for a number times and the players can observe the outcome of the previous game before attending the next iteration [24], [25].

3.2.4. Zero-sum Games

A situation in which one person's gain is equivalent to another's loss, so the net change in wealth or benefit is zero. A zero-sum game may have two or more players. They are usually called strictly competitive games in the game theory discipline, but are less widespread than non-zero sum games [25].

3.3. Game Theory on Network Selection

In this subsection, we will discuss works that use the game theory to solve the network selection problem. As we mentioned above, a game is defined by three sets: players, actions and payoff. In the network case, players can be users, networks or both. A distinction between those categories will be made below.

3.3.1. Game between Users

In [5], authors modeled a competition between users for one access point as an evolutionary game. Users represent players that compete to maximize the transmission rate. The latter represents the strategy, hence the pay-off is modeled by an objective function. This function takes the delay

and packet loss rate and determines the mean opinion score MOS, which is a measure for voice quality. In [5], the notion of free users is used. VoIP is the only service used and the authors claim that the equilibrium reached is optimal.

In [26], the problem of the least congested access point selection is emphasized. The set of strategies contains different access points available and the pay-off is a trade-off between bandwidth gained and the effort generated when moving to the new access point. The authors demonstrate that the result of this game is the distribution of users on the access points.

In [27] authors consider the scenario with a single Wi-Fi network and multiple access points. In this case study, users can choose one access point to connect to, the pay-off function depends on the congestion level of the access point and cost. The authors affirm that the Nash equilibrium is reached.

The works mentioned above suggest that a game between users means that players seek, in general, non-cooperative behavior and because of the selfish nature of users, these games lead to the situation of congestion, and also to the monopolization of resources by certain users.

3.3.2. Game between Networks

When players represent the networks, the latter compete to get the attention of users and maximize the number of users connected, to achieve more revenue. In [28], authors present a non-cooperative game mechanism between networks in which the players compete for a service requirement and try to gain the maximum of an access point. This represents user satisfaction. The problem of this scheme is that the preferences toward players are the same. In [29] authors have introduced the strategy space and quality point concepts, the players are the networks and the pay-off function determines which access network will provide the service requested by the user, which corresponds to the distribution of service requests amongst the networks.

In [30] researchers have investigated the admission control problem by modeling a multi-round game between two Wi-Fi networks. Here, the players in the game are the two networks, and the strategy set is the user's service requests. The pay-off of the game is the distribution of the service requests between the competitive networks.

The papers referred to above prove that games between networks are characterized by one well-known strategy, i.e. by seeking the maximum revenue or maximizing the number of users connected to the network. This approach guides users to think about their corresponding network selection schemes under this network in a competitive environment.

3.3.3. Game between Users and Networks

In this case, players act as mobile users and/or networks. In [31] authors propose a reputation-based network selection mechanism by modeling the interaction between users and networks using a repeated prisoner's dilemma game. To reinforce the cooperation between users and networks,

authors combine the reputation-based systems and game theory. The network reputation factor represents the network's past behavior in the network selection decision. Researchers show that using reputation is essential in the case of cooperation and that repeated interaction maintains cooperation.

In [32] the network selection problem having the form of a non-cooperative auction game is modeled, in which buyers represent users, sellers/bidders are the available network operators and the auction component is the requested bandwidth with its associated attributes. The auction that maximizes the user utility is the winning bid.

In [33] a non-cooperative resource allocation based on the Cournot game between a provider and his customers is presented, where users are classified into three classes: premium, gold and silver. The strategies for the provider and the customer are as follows. The provider seeks customers who bring high revenue, while if the customers are not satisfied from the received QoS, they can decide to leave the network. Users are accepted into the network if the new benefit computed when a new customer arrives is less than the provider's benefit value. Finally, the authors identify the equilibrium for resource distribution. This game type can be summarized in the following manner: users compete against networks, each seeking to maximize their own benefits. On the one hand, users try to maximize their benefits (cost- and/or QoS-related). On the other hand, the networks try to maximize the profit for the services provided.

3.4. Fuzzy Logic

In fuzzy logic, there are few degrees of satisfaction of a condition [34]. Unlike in Boolean algebra, where a proposal is considered to be true or false, fuzzy logic adds a degree of truth to choose from the $0\ldots1$ range. It is a tool of artificial intelligence used in various fields [35]. The concept is based on the theory of fuzzy sets with an extension of the classical theory. Fuzzy logic brings the concept of partial truth, where the truth value may vary from completely true to completely false.

3.4.1. Fuzzy Logic in Network Selection

A few studies have addressed the network selection problem using fuzzy logic as a core of the ranking scheme. Basically, authors use fuzzy logic in network selection in two ways: as a combination of MADM and fuzzy logic, or they use it as the selection scheme.

In [6] authors propose a general scheme to solve the multi-criteria network selection problem. In the proposed scheme, the multi-criteria network selection solution is obtained by considering the users' requirements and QoS. The proposed scheme is scalable and is capable of handling any number of RATs with a large set of criteria. The simulation results show that the proposed solution has a better and more robust performance over the reference solutions.

In [36] researchers describe two novel, fuzzy logic based ranking schemes. These schemes enable users to evaluate the correctness of different combinations of P2P-based grid

networks. A fixed set of commonly used attributes is used, such as cost, capacity and reliability. The proposed ranking algorithm is based on an intuitive rule optimization design applying Boolean logic to capture input combinations.

In [37] authors propose a fusion method-based fuzzy logic approach for different network schemes. The main advantage is the consideration of the relative importance of different networks. The authors show that the proposed scheme significantly improves the generalization capability.

Most of the recent works using the fuzzy logic are combined with MADM methods [38], [39]. Generally, in the field of network selection, the use of fuzzy logic as a core of the ranking scheme is not widely adopted. Instead, fuzzy logic has always been combined with MADM.

3.5. Utility Functions

Utility is the "satisfaction" we get from using, owning or doing something. It is what allows us to choose between options.

A preference function utility assigns values to the ranking of a set of choices. This is useful in analyzing consumer behavior in the maximization problem. Faced with a set of options and a budget constraint, we will choose what satisfies them to the highest degree. Utility functions are often expressed as $U(x1, x2, x3)$, which means that U (utility) is a function of the quantities of $x1, x2$ and so on. In the case of monotonic functions, if A is a set of goods, and $A > B$, then $U(A) > U(B)$. That is, if A is preferred to B.

For making a decision, utility refers to the level of satisfaction that goods or a service provide to the decision maker [40]. Utility function is an associated term which relates to the utility derived by a consumer from goods or a service. Different consumers with various user preferences will have different utility values for the same product. Thus, the individual preferences should be taken into account in the utility evaluation.

In the paper [41] authors show that many of the commonly used MADM algorithms, such as SAW, WPM and TOPSIS, in their standard form, are not best suited because of

their assumptions concerned with a monotonous increase or decrease of the attributes' utilities. They affirm that both monotonic and non-monotonic utilities can be taken into consideration, and are therefore better suited for achieving this type of optimization objectives.

In [42] researchers proposed a user-centric RAN selection strategy based on maximizing consumer surplus, subject to meeting user-defined constraints in terms of transfer completion time. An exploration of a number of possible utility functions based on different user's attitudes to risk is presented. They affirm that simulations produced results that correspond to the user utility descriptions input. The risk taker ends up paying more, but enjoying less delay.

In [43] researchers proposed a user-centric RAN selection strategy based on maximizing consumer surplus subject to meeting user-defined constraints in terms of transfer completion time. An exploration of a number of possible utility functions based on different user's attitudes to risk is presented. They affirm that simulations produced results that correspond to the in-putted user utility descriptions. The risk taker ends up paying more, but enjoying less delay.

In [44] the researchers have proposed a method called SU-TIL, which is a mechanism for network selection in the context of next generation networks. It prioritizes networks with higher relevance to the application and lower energy consumption, enabling full and seamless connectivity with mobile devices and applications. They even propose some future works, such as conducting an investigation to address the interaction between multiple instances of SUTIL and consideration of the highly dynamic nature intrinsic of the environments where SUTIL operates.

4. Analysis and Discussion

Figure 3 presents the approaches described in this paper. At the top of the flow chart is the NS problem, in the second row different approaches and their categories, namely MADM, game theory, fuzzy logic and utility functions are placed. Each category has its own specific methods
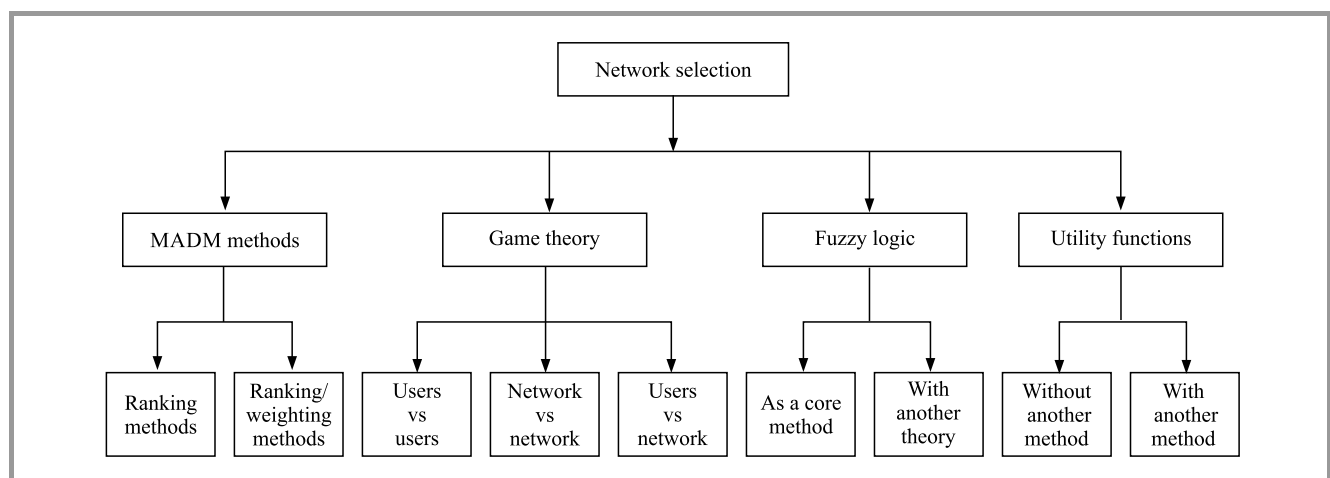

Fig. 3. Summary of NS methods used.

Table 5
Summary of the discussed methods

Type	Advantages	Disadvantages
Ranking methods	Easy to understand and use Relatively good results Low complexity	Rank reversal phenomenon Lack of a weighting process Different behavior with various applications
Weighting/rating methods	Weighting process	Rank reversal phenomenon High complexity
Users vs. users Users vs. networks Networks vs. networks	No rank reversal phenomenon	Selfish behavior of users lead to the congestion
As a core method With another approach	Overcome the MADM's drawbacks	Few works in the literature Time consuming due to coupling two approaches
Without other methods With another approach	Solving simple problems Powerful and used in many works Overcome the MADM's drawbacks	Few works in the literature

(if such exist), which are regrouped in the bottom row and are summarized in Table 5:

- Ranking methods. TOPSIS, SAW, WPM and others – methods which require another method to obtain the weight vector. Such methods suffer from a lot of problems, such as the rank reversal phenomenon, and the influence of a bad value of a criterion on the good value of another criterion.

- Ranking/weighting methods. These methods suffer from high complexity and rank reversal, which can occur here as well, because it is a problem affecting the entire MADM approach.

- Game theory. Game theory is a good tool to model the network selection problem. The main concern is the computation time, due to the relatively high complexity degree. This issue may be avoided in the case of a game between networks.

- Fuzzy logic. It has been adapted to solve the network selection problem but, generally, it is not used alone, it needs to be accompanied by MADM methods or genetic algorithms.

- Utility functions. The utility function is used with other methods, such as fuzzy logic or MADM, and it can also be used in a unilateral way.

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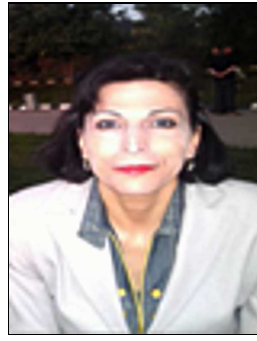
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