Baltic J. Modern Computing, Vol. 10 (2022), No. 1, 55-70
https://doi.org/10.22364/bjmc.2022.10.1.04

Review of Mobile Connectivity Persistence Technologies for Dynamically Changing Networks' Availability Scenarios

Leo TRUKSANS, Ieva LAPINA

Institute of Mathematics and Computer Science, University of Latvia,
Raina blvd. 29, Riga, LV-1459, Latvia

leo.truksans@lumii.lv, ieva.lapina2@lu.lv

Abstract. Given the variety of network connectivity options for mobile devices, dynamically choosing the most optimal connection between multiple alternatives is not a simple process. In heterogeneous networks with changing availability the decision process plays a significant role in ensuring a persistent and seamless connection. This study analyses existing technologies and methods for evaluating the quality of computer network connections aimed at finding the best time to change networks and selecting the best connection available at a given time. A study of theoretical literature is carried out, examining the selection method processes and their importance in ensuring mobility. The most universal in the context of this study is found to be the SAW method.

Keywords: Heterogeneous wireless networks, Handover decision, Seamless connectivity, Roaming connections, Always best connected.

1. Introduction

Depending on the mobile device used and the surrounding environment there may exist a large amount of radio access technologies (RAT) that can be used for communications. For instance, a mobile phone generally supports wide variety of technologies, such as cellular networks (GSM, UMTS, LTE, 5G, etc.) and local or smaller networks (Wi-Fi, Bluetooth, NFC, etc). Given that all these technologies can overlap, the set of those may be viewed as a kind of hybrid network, known as a heterogeneous wireless network (Zekri et al., 2012). It can be defined as a multi-technology environment, where end devices can freely roam between these access technologies, making connections as needed. In relation to heterogeneous networks and the desire to be always connected, the concept of “Always best connected” (ABC) has emerged (Gustafsson and Jonsson, 2003). ABC aims to find the best possible connection through predefined rules and parameters in an environment where different access technologies are available.

Continuous access regardless of location and movement can be achieved by using large number of access points within a wide geographical area and end devices that can connect to a variety of technologies. In the studies of heterogeneous networks one of the problems studied is how to determine the best possible connection from the available ones when networks are constantly changing (Goyal et al., 2017). To have a persistent connection it is necessary to keep up with the available networks and their quality in order to, if the need arises, allow a handover to a new access point. The handover process from one access point to another is a complicated procedure, that includes the decision of choosing the best connection.

Depending on networking technologies available, horizontal or vertical handover can be used (McNair and Zhu, 2004). Horizontal handover means that a mobile terminal changes connections between one type of access points, for example, two Wi-Fi stations. Vertical handover entails switching between different technologies. This allows to get the best aspects from each technology used, but it may require extra measures for connection comparison (Obayiuwana and Falowo, 2017; Srivastava and Misra, 2016).

Handover process itself can happen in different ways called soft or hard handover (Sivvam et al., 2018). Hard handover can be executed firstly by disconnecting from the current connection and then connecting to the new one. This means that at some point between the two phases the device has no active connection. Otherwise, the device can first connect to the new access point and only then disconnect the previous one. This is called soft handover. The device will always have an active connection during the handover process. It should be noted that the possibility to be connected to multiple networks at the same time is dependent on the device used.

Last major handover classification is the reason to do handover (Sivvam et al., 2018). It can be done based on need or the so called voluntary transition. In the former approach interest for new connection arises only when the current one is deteriorating so handover happens based on need. In the latter approach the connection may also be changed if it is good enough, but there is a better connection than the current one. In this case there is a continuous monitoring of alternatives with a goal of finding an even better connection.

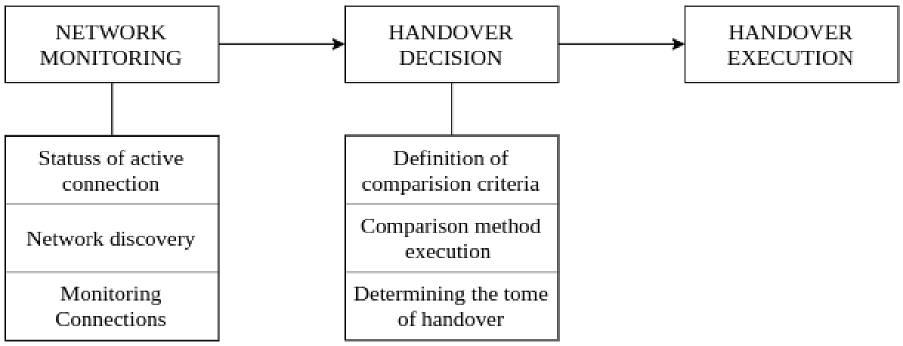

Fig. 1. Processes included in the connection handover

Handover consists of multiple steps (see Fig. 1). Usually it is divided in connection monitoring, decision making and handover itself (Goudarzi et al., 2015). Connection monitoring collects information about available connections and their quality parameters. Information that is collected during monitoring process is used to make a decision. Then, a quality comparison method is used, that can give a definitive answer about the need to switch connections. The last step is to do the handover if the appropriate decision has been made. All three steps need to work fast and united to provide seamless handover between different networks.

In terms of choosing the best connection, different types of strategies may be used, which differ based on who assesses the alternatives and who makes the final decision as seen in Figure 2. In one case the decision could be made in centralized fashion on the side of the operator. Decision is based on the basis of customer allocation by available access points, nearby networks and their working capacity and on policies defined by network providers (Sgora et al., 2009). The decentralized way is to make a decision at the clients side, where the decision is made by the device or the user itself.

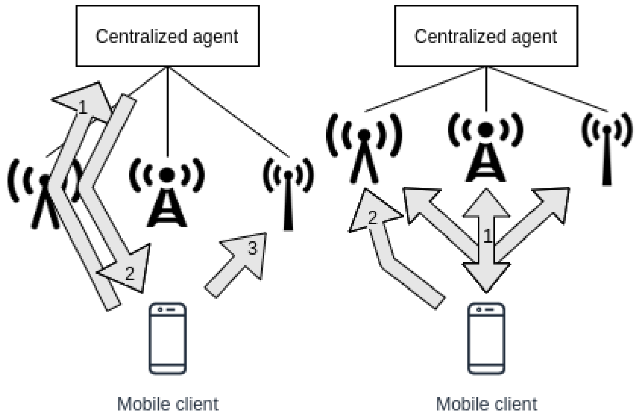

Fig. 2. Connection decision process between multiple access points: (a) Centralized decision-making: 1) client transfers information to the centralized agent through the existing connection, 2) agent determines the optimal connection and sends the information to the client 3) customer executes handover (b) Decentralized decision making: 1) client collects information about available connections and chooses the best 2) client executes handover

Other strategies that are hybrids between centralized and decentralized approaches may be distributed. For example, one approach could be for end device to receive some necessary information from an agent on the network. Since we are looking to have connectivity regardless of provider or network type, only decentralized method is studied in this paper.

2. IEEE 802.21 and protocols for continuous mobility

In 2009, IEEE published framework 802.21, which is referred to as MIH (Media Independent Handover). It aims to facilitate a rapid and seamless transition between different radio access technologies. MIH framework provides a standardized way for network detection, selection and handover between networking standards in the IEEE 802 group and cellular technologies. MIH consists of three services (see Figure 3) (Fratu et al., 2011):

- Media Independent Event Service (MIES)
- Media Independent Information Service (MIIS)
- Media Independent Command Service (MICS)

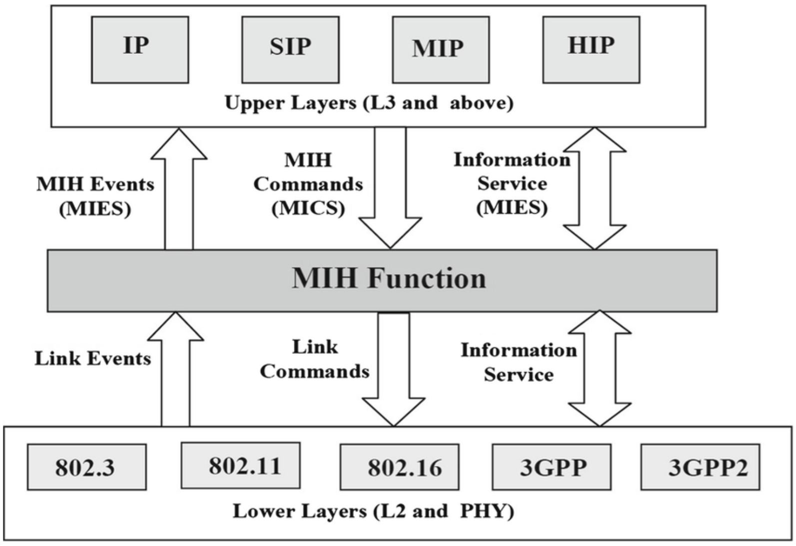

Fig. 3. Media independent handover framework (Fratu et al., 2011)

MIES follows changes in the lower layers (physical, data link). For example, whether the connection has been established and is active or has it stopped working or will do that soon. MIIS is responsible for collection of information on cases such as access point locations, relevant service providers, usage costs, safety concerns, QoS data and other information that can aid in the decision making process. MICS based on information provided by MIIS and MIES allows MIH client to initiate certain command such as handover initiation and execution.

It should be noted that the functionality of this framework does not include carrying out the handover process itself. The MIH framework itself does not make any decisions, it merely defines a mechanism to allow the parts involved to interact with each other. The connection selection procedure depends on the implementation by the developers and is not defined in the protocol itself.

The MIH framework has not been extensively implemented. There are a number of attempts at introducing continuous handover using MIH. This is usually done in addition to one of the mobility support protocols, such as MIP or SIP, which are responsible for the continuity of sessions. A survey of mobility support protocols can be found in (Zhu et al., 2011). One study proposes a mobility solution using MIH and MIPv4. Study presents a client/server model that uses tunnelling mechanism to ensure continuity of sessions by switching between different wireless technologies. Best network is selected based on throughput measurement. Another similar study analyses the latency of handover process using a combination of MIH and ProxyMIPv6 standard (Song et al., 2011). As a result it concludes that the addition of MIH helps to reduce latency as different access technology methods do not need to be used.

Independently form IEEE802.21, the 3GPP at almost the same time developed Access Network Discovery and Selection Function (ANDSF) which like MIH aids in finding and choosing the best network. It allows to discover both 3GPP and non-3GPP networks. Based on this mechanism, when clients device connects to mobile network, ANDSF server transfers mobility policy and the network discovery information to the users device. End device in the opposite direction to the ANDSF server forwards information about its location. Based on this information exchange client side can choose the best network (Yang et al., 2016).

For session continuity, the connection handover protocols are supplemented with mobility support protocols. They aid the handover process by saving running sessions while connection changes from one access point to another. It is done by maintaining original IP addresses of session or linking a new address to the old one. Previously mentioned MIP protocol is one of the options. It works on the principle that when a user moves between networks, two IP addresses are maintained that help to identify the device independently from the devices location (Zhu et al., 2011).

A notable widely used implementation of continuous usability can be found in Apple's iOS feature "Wi-Fi Assist". Because Apple's iOS is closed-source, it is difficult to know exactly how this feature is implemented. But from users perspective, when the feature is activated the switch between cellualar and Wi-Fi will happen automatically if a poor Wi-Fi signal is detected (WEB, a).

3. Criteria for selecting a connection

To make a choice between available connections it is necessary to identify metrics that allow quantitative comparisons between different connections. Making decision can be considered a very complex problem, as there is a wide range of criteria to be applied and their combinations, which in some cases may even conflict with each other. If multiple criteria are used there exists a large amount of combinations that each implementation chooses to use (Márquez-Barja et al., 2011).

To evaluate available connection, network-specific metrics can be used. In wireless connections, one of the most common characteristics is the signal strength or signal power. However, QoS parameters could be as important in the selection process. Also important is need to use parameters that provide information on the capabilities of the end devices. It is particularly important to know what kind of interfaces are available, as this would indicate what type of connection technologies this equipment can use. Similarly information on the geographical location of the equipment, the speed of movement of the equipment and the battery capacity could influence the final decision. Depending on which applications the client uses at any specified time, the needs of the programs may also vary. The last significant criteria group can include user expectations. Users may have specific service quality requirements or even a preference for a specific technology. Similarly, end-users may have a certain threshold for monetary costs, as well as security considerations.

When analysing the criteria to be used, it is important to understand what information is available at once and what information should be obtained by measurement or demand. The handover decision should not be influenced by the speed of measurement analyses. A static criterion that can be read instantly will not have a big effect on operation speed. In contrast dynamic criterion will need extra time to monitor and compute the results.

It is just as important to assess how accurate the corresponding values are and how dynamically they change or can change in the near or distant future. A criterion such as signal strength may have a very rapid fall or increase in real world conditions. It is important to understand how quickly it will be possible to react to these changes and to appropriately assess the impact of the use of these criteria on the final results.

4. Selection methods

Research literature offers a variety of network selection techniques that try to achieve the ABC strategy. Each method has its own level of complexity, flexibility and credibility. Typically the methods are based on an algorithm that selects the best connection by using the predefined criteria as variables in the function. Some of the most mentioned methods in the literature are examined within the scope of this section. For each of the methods the selection procedure, the applications offered in the literature and analysis of the methods is looked at.

4.1. One criterion method

Traditionally wireless networks use one criterion to make the decision. Typically it is the received signal strength (RSS). But between different types of radio networks it is improper to use relative RSS value because its range varies across different radio networks, thus producing incomplete results. When comparing between different types of networks additional computations or parameters must be used. The method of one criterion has very low complexity and fast computation. However it is not always a reliable characteristic, which can lead to the fact that the results obtained do not represent the true state of the connection. Nor does this technique include user, device or application needs that could affect the choice of best connection.

Given that several network options could be with similar results evaluation process is usually supplemented with additional comparison techniques that help determine the need for handover and the time when to execute it (Lal et al., 2007). These techniques are usually used in one criterion method but they can also be found in other methods. These techniques appear with different names based on implementation but in this case they will be called: threshold, hysteresis and waiting timer. All three techniques can be used at the same time, but depending on their application they may be also used in different combinations.

Threshold technique indicates a metric value that when surpassed or dropped below activates the handover or related processes. Threshold can be used in different ways, for example if the current connection has a sufficiently good signal strength above set threshold, it is not worth switching to another connection. Or, if a possible alternative network surpasses a threshold it can be regarded as a good alternative.

In case of hysteresis, it is taken into account that the values constantly change in some fluctuating range. Thus, under of influence of hysteresis, potential network comparison results can be considered to be at the worst possible fluctuation by subtracting a certain value form all measurement results. Often hysteresis technique is simply called measurement offset.

Waiting interval mainly helps to mitigate the ping-pong effect where a device constantly shifts between two or more networks. It is done by implementing a wait or sometimes called dwell time for a certain interval until a new transition can be made. It is expected that results for the potential connection stay stable and do not deteriorate within the prescribed time interval. If the results degrade during wait period, the time shall start from anew. Waiting time can easily be combined with threshold, so that the counting starts when measurement goes above or below certain values. Waiting time often is adjusted depending on the movement speed of the mobile device to adjust to the measurement change time. In (Kunarak and Suleesathira, 2020) a simulation is done that shows differences in amount of handovers with and without dwell time.

As an example of this criterion method, the standard for LTE mobile networks may be considered (WEB, b). It uses signal strength to compare connections by deploying an event reporting system that records changes of measurements of available connections. In principle, events include different cases of exceeding the threshold and comparing the measurement of connections, in specific cases also including hysteresis.

4.2. Multi-criteria methods

Multi-criteria methods include techniques that primarily aim to compare a range of potential candidates. It is done using a number of criteria that can describe the differences between all the alternatives. Result of using these methods gives a sorted list of all the alternatives based on the used criteria and their importance. These methods are also widely used outside of network qualification, for example they are often used in stock markets. A large number of multi-criteria methods exist with its own specific characteristics and application techniques, so it is not possible to highlight one specific method that is superior to others. Some commonly used methods will be looked at.

4.2.1. SAW method. Simple additive weighting (SAW) or cost function in other literature is one of the easiest assessment methods that helps to rank potential candidates, by determining whether there exists any benefit to choose another alternative instead of the current one. As a result the network with the smallest estimated cost size is the network that is the best choice in the appropriate situation. Functions general formula for calculating networks n cost size f_n is given in formula (1) (McNair and Zhu, 2004).

$$f_n = \sum_{s} \sum_{i} w_{s,i} \times p^n_{s,i} \qquad (1)$$

Function evaluates the network based on the services and criteria used where $p^n_{s,i}$ denotes cost for criterion i to do service s in network n, but $w_{s,i}$ .weight for criterion i to do service s. In some cases, it is used without service breakdown (Hong et al., 2009). In that case, networks are evaluated according to the parameters selected and their weights. Corresponding weights for each criterion are selected depending on the importance of the criterion, assigning a value between zero and one, taking into account that the sum of all weights must be equal to one. When selecting this method a good knowledge of the criteria used is needed, as different weights will result in appropriate changes in the results. Given that the purpose of the cost function is to find a network with the lowest result, if a criterion exists that requires the value to be as high as possible, then an inverse value should be used.

The first time, the cost function was proposed for use in the process of selecting the best network was in 1999 (Wang et al., 1999). In work, its authors offer a mechanism for selecting best connection, which includes comparing networks by their cost values. The work suggests that mobile users themselves could determine the weights to be used in the network selection process for each parameter. It may not be the most appropriate solution as end users may not be knowledgeable enough to make these decisions.

Articles that offer solution using cost function use it according to their required situation. In one work connections are compared using cost function, however WLAN networks are always preferred if the choice is between WLAN and WWAN connections as they usually have higher available bandwidth and lower monetary costs (Hong et al., 2009). Another work suggests a way to optimize the network selection process so that the cost function is calculated and the delays that may occur during the calculation are relieved (Zhu and McNair, 2004). This is achieved by introducing a network shutdown factor that helps to identify networks that do not meet the required requirements. For example, if a connection is unable to provide a minimum delay time for a real-time service, it should be removed immediately from the list of potential candidates. Another source offers a modified SAW algorithm called Enhanced SAW (E-SAW) (Maaloul et al., 2013). This algorithm involves exclusion of invalid connections before the main SAW evaluation, thus saving on result computing time.

4.2.2. MEW method. Another algorithm that uses weights to determine the results is Multiplicative exponent weighting (MEW) or in other literature Weighted Product Model (WPM) (Savitha and Chandrasekar, 2011). The method is quite similar to SAW's technique. The main difference is that the criteria are multiplied, not summed with each other. MEW functions formula to get *i* networks result *A* using *j* criterion where *w* denotes weight for criterion and *x* is the value of criterion is as follows:

$$A_i = \prod_j x_{i,j}^{w_j} \tag{2}$$

Because MEW uses exponents and data is raised to the power of weights value, calculations become fractional exponents that can be harder to calculate, and will very rapidly attain a large number of decimal numbers. Depending on monitored criteria values it has a possibility to develop into very small numbers that can not be easily saved onto memory.

4.2.3. AHP method. The method of the analytical hierarchy process (AHP), divides the best connections selection process into a hierarchical way in different levels to facilitate the evaluation process by dividing it into smaller tasks. The top of the hierarchy shows the goal that need to be reached, while the available alternatives lay at the very lowest level, with sub levels filled with selection criteria. Based on this hierarchy, procedures may be carried out that will result in calculation of weights that are to be assigned to each criterion for each alternative.

Table 1. AHP pairwise comparison scale

Intensity of importance	Explanation
1	Both elements contribute equally
3	Slight favour on one element over another
5	Strong favour on one element over another
7	Element is strongly favoured over another and its dominance is demonstrated in practice
9	Absolute importance of element over another element
2,4,6,8	Intermediate values used as compromise between two adjacent judgments

First step in calculating the weights is to draw up a pair comparison matrices. With the help of matrices qualitative judgments are transformed into numerical values.

Matrices are created by comparing how important each of the criterion is relative to another criterion at the corresponding hierarchical level. This is done using a special 9-point intensity of importance scale that helps to assess the significance of each criterion (Table 1). On the scale, the value 1 indicates that the two comparable criteria are equally important and have an equal impact on the expected result. Conversely, value 9 indicates that one of the criteria is extremely more important than the other and that the change in this criterion should also have a significant impact on the resulting value.

Using the scale specified in Table 1, a matrix X can be created in which the element x_{ij} is obtained by evaluating the i-criterion relative to the j criterion, or each element in the matrix row is evaluated relative to each element in the column (3).

$$X=[x_{ij}]=\begin{bmatrix} 1 & x_{12} & \dots & x_{1n} \\ 1/x_{21} & 1 & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ 1/x_{n1} & 1/x_{n2} & \dots & 1 \end{bmatrix}, 1 \leqslant i, j \leqslant n \quad (3)$$

According to the matrix formula (3), you can see that when comparing the criterion to itself, the value will always be 1, i.e. for all i, $x_{ii} = 1$. In addition, if $x_{ij} = Y$, then $x_{ji} = 1/Y$, which means that only n(n-1)/2 criteria should be compared in the n×n dimension matrix.

For criteria weights, it is necessary to calculate the priority vector. To do this, the created matrix is modified so that the sum of each column is 1. This is done by dividing each element of the matrix by the sum of its corresponding column. Then, the arithmetic mean value is found for each row, which creates a priority vector when combined.

Because comparison uses a person's subjective judgment, it is necessary to carry out procedures for verifying consistency. For example, if the signal strength is more significant than bandwidth and the bandwidth is more significant than the delay time, it follows that the signal strength should be more significant than the delay time. If this is not the case, there are illogical data that will not produce the correct results. For consistency comparison purposes, the author of AHP method established a consistency ratio formula (Saaty, 2000).

Given that AHP helps to determine what weights should be assigned to each of the criteria, this method is sometimes proposed to be combined with another multi-criteria method. In one of the literature sources, AHP is combined with Grey relational analysis (GRA) method (Fu et al., 2010). As a result, parameter weights are obtained using the AHP method, but GRA is used to calculate the result using these weights. A similar solution is proposed by combination of AHP with TOPSIS method (Goyal and Kaushal, 2019), that will be looked at next.

4.2.4. TOPSIS method. Techniques for Order Preference by Similarity to Ideal Solution method aims to find the best alternative closest to the perfect solution, but furthest from the worst case. The best and worst solutions are obtained on the basis of the amplitude at which the values of the selected criteria are available. Thus, the best alternative is to consider the connection, which is closest to the best solution using Euclidean distance and farthest away from the worst solution.

TOPSIS procedure involves several steps (Yoon and Hwang, 1995). A normalized array of choices is first constructed between the alternative connections *i* and the criterion *j* (4). The weighted normalized matrix is then calculated using the predefined weights w_j (5). The third step sets out the ideal (A+) and negative ideal (A–) solution (6). J_1 is accepted in this function if it is a benefit criterion (the value must be as high as possible) and J_2 if it is a cost criterion (the value must be as low as possible). On this basis, the distance to the best (Si+) and worst (Si-) solution is defined for each of the alternatives, using the Euclidean distance (7). As a result, for each alternative, close proximity to the ideal solution can be calculated (8)). The results can be arranged in ascending order, where an alternative with the highest result is the best solution.

$$r_{ij}=\frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}}, i=1,\dots,m; j=1,\dots,n \quad (4)$$

$$v_{ij}=r_{ij}\times w_j \quad (5)$$

$$A^+=\{v_1^+,v_2^+,\dots,v_n^+\}=\{(\max_i v_{ij}|j\in J_1),(\max_i v_{ij}|j\in J_2)|i=1,\dots,m\}$$
$$A^-=\{v_1^-,v_2^-,\dots,v_n^-\}=\{(\min_i v_{ij}|j\in J_1),(\min_i v_{ij}|j\in J_2)|i=1,\dots,m\} \quad (6)$$

$$S_i^+=\sqrt{\sum_{i=1}^{n}(v_{ij}-v_j^+)^2}$$
$$S_i^-=\sqrt{\sum_{i=1}^{n}(v_{ij}-v_j^-)^2} \quad (7)$$

$$P_i=\frac{S_i^-}{S_i^+ + S_i^-} \quad (8)$$

Literature offers a number of enhancements to TOPSIS method, which help to optimize the process of selecting connections. Two different methods of improvement are proposed in one of the sources (Alhabo and Zhang, 2018). One of the methods uses entropy to determine weights for criteria. In the other method, it is proposed to use the results of standard deviation in the determination of weights. Mostly, the second method produced better results, but in the case of small network cells, the first method was the dominant one. The study (Lahby and Sekkaki, 2017) compares method of TOPSIS and the method of cost function. The work concludes that using the TOPSIS method provides better results between data flows, looking at background, talk, interactive, and streaming flows.

4.2.5. Analysis of multi-criteria methods. There are a number of studies that have attempted to compare several of the techniques in terms of the quality of the networks. The most frequent purpose of such works is to conclude which methods are better applicable according to data objectives and what criteria are optimal for the different techniques.

The publication (Obayiuwana and Falowo, 2017) provides an extensive overview of the multi-criteria methods used in the comparison process. It looks at 10 different multi-criteria methods. For each of the methods its working process and use0 in other studies is looked at. The work does not include a broad comparison of methods, but it outlines how the choice of criteria and weights can affect final results. The work also presents results on the frequency of using different criteria for each multi-criteria method. There you can see that the most commonly used criteria are bandwidth, monetary costs, delays, delay fluctuations and packet loss rates.

A practical comparison of multi-criteria methods was carried out in a 2010 study (Martinez-Morales et al., 2010). In the work its authors analyse different methods for voice and data connections on 4G networks. The main findings in the work indicate that

SAW and TOPSIS methods are well-suited for voice data connections, resulting in a smaller packet delays, while GRA, MEW and ELECTRE techniques are better for use in data connections, resulting in better throughput.

4.3. Fuzzy logic method

Multi-criteria methods include techniques that primarily aim to compare a range of potential candidates. The decision-making structure of the fuzzy logic may be divided into three steps: data fuzzification, conclusion making and data defuzzification. At the data fuzzification stage, the input data is converted from binary logic to fuzzy logic. At the conclusion stage, conclusions on the decision to be taken are drawn on the basis of the data and decision-making rules established. In the final phase, the final conclusions are defuzzified by turning them back into binary logic. In Figure 4, you can see graphically how the decision-making process of the fuzzy logic is taking place.

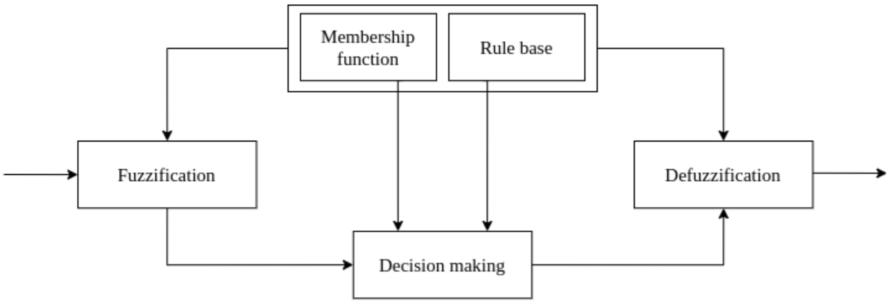

Fig. 4. Decision making process using fuzzy logic

For data fuzzification, it is first necessary to define the linguistic values of logical variables for each of the parameters to be used in the decision-making process. For example one criterion value could be: “bad”, “medium” and “good”. Further, each of these groups needs to define the area and membership functions of the values that are acceptable to them. The value area is all the values that a variable can accept in the corresponding group. Based on these sizes, a home function is created. In order to do this, each value in the defined area must be assigned a degree of membership in the interval [0; 1]. The formula (9) shows one way that membership function may be defined. The display of this function in the coordinate plane can be seen in Figure 5, which shows all three linguistic features.

$$\mu(x)=\begin{cases} 0 & , if\, x \leq 35 \\ \frac{x-35}{15} & , if\, 35 < x \leq 50 \\ 1 & , if\, 50 < x \leq 65 \\ \frac{85-x}{20} & , if\, 65 < x \leq 85 \\ 0 & , if\, x > 85 \end{cases} \tag{9}$$

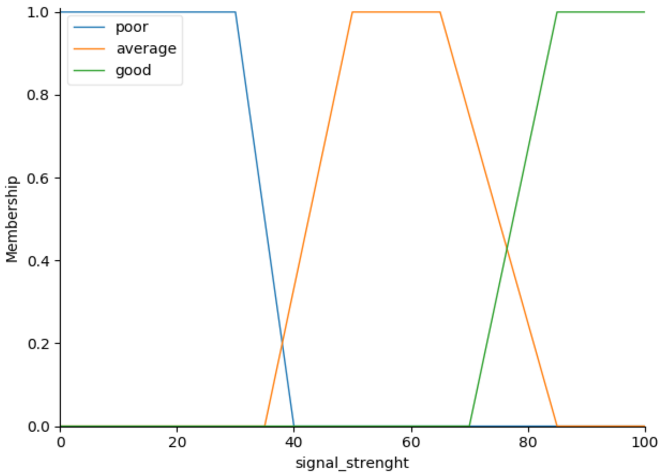

Fig. 5. Decision making process using fuzzy logic

Membership functions can be defined as straight lines, as in this case, or they can be defined in the form of curved lines using, for example, Gauss distribution (Tsai et al., 2016). As a result, when the entry values are received, they are allocated to the corresponding linguistic group, using membership functions. If a value belongs to more than one function, a union of the two functions may be considered where the largest value of both functions is taken, or a intersection of both functions in which the smallest of the values of both functions is selected (Lootsma, 2013).

In order to arrive at any conclusions on the data provided, it is necessary to define the rules for the decision making. The rules are written in "IF...THEN..." shape. Most often rules consist of a combination of several parameters associated with "AND", "OR" and "NOT" operators. Based on how many parameters are used and how many linguistic values each parameter is allocated, the number of rules to be defined will also change. Lastly, it is necessary to defuzzify the result. One of the most common defuzzification methods is the use of a centre of gravity that returns the centre value to the area under the home function (Takagi and Sugeno, 1985).

In one of the publications, fuzzy logic is used to reduce the ping-pong effect on mobile networks when the machine moves between the borders of several base stations. In this work, the signal-to-noise ratio, bandwidth and device power were used as criteria. The results obtained indicated that the use of fuzzification was able to reduce unnecessary switching between networks by 68% and to eliminate ping-pong effects by 92% (Tsai et al., 2016).

Another publication offers an algorithm that determines the quality of the network using three criteria: RSS, the speed of the mobile machine, and the load of access points. The proposed solution offers the normalization of heterogeneous network data using fazzification. The algorithm provided is valid only for low movement speed networks. However, when a device is moving at high speeds, a 15%-50% probability of failure to switch the connection is observed, which makes it impossible to use the solution in real-time systems (Wu, 2011).

5. Comparison of methods

The selection methods that have been studied so far are trying to find the best connection in a variety of ways. On the basis of the theory analysis, Table 2 makes a concise comparison between the methods discussed in this work. The following section will briefly describe the results of each method against the selected criteria.

One of the main criteria in the comparison process is the possibility to do so using a number of criteria. Using one criterion method it is not possible but in the other methods examined, the number of comparison criteria can be chosen freely according to the situation. Next comparison parameter includes the condition that user expectations are represented in the network choice. Because one criterion method is usually based solely on connection quality information it does not include user expectations in results adoption. The other methods examined may take into account user need, depending on the criteria selected. In the case of multi-criteria methods, the comparison criteria may weighted to appropriate representation. Similarly, in the fuzzy logic method, the results can be adjusted according to different preferences using membership functions. The

Table 2. Comparison of decision methods

Comparison Criteria	One criterion method	SAW	MEW	TOPSIS	AHP	Fuzzy logic
Multiple criteria	-	+	+	+	+	+
Core Process	Best value	Weighted sum	Weighted product	Distance principle	Hierarchy principle	Fuzzification
User need inclusion	-	Depending on used comparison criteria				
Application context identification	-	Medium	Low	Medium	Medium-high	High
Implementation, usage complexity	Low	Low	Medium	Medium-high	Medium-high	High
Adaptability	-	Medium-high	Medium-high	Medium-high	Medium-high	Medium
Efficiency	Low	Medium	Medium	Medium	Medium	High

“application identification context” criterion indicates the possibility to change settings for the selection process based on what the connection is intended for. This means that the method should allow to compare connections in different ways, depending on what type of data will be sent through the connection. Multi-criteria and fuzzy logic methods have options that can help to influence the decision making based on different services or data flows used, but one criterion function because it is very static has no option in this regard.

One criterion method will be the easiest to use, especially if signal strength is the chosen criterion as it requires no active monitoring. Multi-criteria methods depending on the algorithm can be quite simple in case of SAW method that requires very few calculations to TOPSIS and AHP that will need more steps to get the result. Fuzzy logic in this case will be the hardest to implement as it takes a lot of complex calculations that get exponentially larger as more criteria are used. All methods are quite effective at determining the best option, but using one criterion it is not possible to represent all aspects of the connection, that can be done using only multi-criteria or fuzzy logic methods that can look at the problem from different sides. Lastly in case of heterogeneous networks it is extremely important to have the option to compare networks using different access technologies. Depending on the criteria used one criterion method may need some extra data modifications to be able to compare different technologies. Same goes for multi-criteria methods that will need normalized data to easily compare different networks. Because fuzzy logic already involves data transformations no extra steps will be needed to use this method between heterogeneous networks.

All the methods have their different specific aspects that make them appropriate to be used in different scenarios. If rapid results are required, the traditional one criterion method is the best option. It may not represent the most correct results, but if a small fault tolerance is acceptable it is the easiest and fastest one to implement. To get more optimal results some kind of multi criteria method should be chosen. If computation time is not critical then with good configuration fuzzy logic can present very good result although it will require a lot more device energy and time. For accurate and stable results that do not require so much calculations SAW or TOPSIS multi criteria methods can be chosen. For only two networks TOPSIS gives extreme data, so it is not particularly a universal solution, but it can be a good option if comparisons will happen between a large amount of connections at the same time. Because MEW uses exponents and data will be raised to the power of weights value calculations become fractional exponents that can be harder to calculate, and will very rapidly attain a large number of decimal numbers. Depending on monitored criteria values it has a possibility to develop into very small numbers that can be easily saved onto memory. SAW method does not require large amounts of calculations and it can use large amounts of criteria. Hardest thing to adjust for this method would be the weight values to get the most optimal results. But with a bit of knowledge this method can be used even in heterogeneous networks without sacrificing time and computing power.

6. Conclusion

This paper included an overview of the handover decision processes that aim to sustain connections while mobile devices move from one network to another. Main goal of handovers is to maintain network connectivity continuity by finding the proper time to switch networks and calculating the most appropriate networks based on every sides needs and capabilities. Six prominent comparison methods where analysed: One criterion, SAW, MEW, AHP, TOPSIS and Fuzzy logic. If vertical handover is needed where switch happens between different technologies it can be seen that traditional handover strategy using one criterion is not sufficient. Thus a more complex strategy needs to be implemented that could take into account more data. Multi-criteria solutions in this case are the best solution.

The most appropriate method will differ based on implementation, but overall among the most optimal, easiest to use, implement and modify depending on needed context will be the SAW method. Other methods in their results and complexity are not far off and in some cases could be the better choice. Particularly, if more computing resources and longer calculation times are allowed, fuzzy logic could present high proficiency results.

Acknowledgments

The research has been supported by the European Regional Development Fund project "Multidimensional room and area scanning system (TADSS)" (No. 1.1.1.1/18/A/139)

References

Alhabo, M., Zhang, L. (2018). Multi-criteria handover using modified weighted TOPSIS methods for heterogeneous networks. *IEEE Access, 6,* 40547-40558.

Fratu, O., Boucouvalas, A. C., Gavrilovska, L., Prasad, R. (2011). RIWCoS: Possible approach for the reconfiguration of the hybrid wireless access networks. In *2011 2nd International Conference on Wireless Communication, Vehicular Technology, Information Theory and Aerospace & Electronic Systems Technology (Wireless VITAE)* (pp. 1-5). IEEE.

Fu, J., Wu, J., Zhang, J., Ping, L., Li, Z. (2010). A novel AHP and GRA based handover decision mechanism in heterogeneous wireless networks. In *International Conference on Information Computing and Applications* (pp. 213-220)

Goudarzi, S., Hassan, W. H., Anisi, M. H., Soleymani, A. (2015). A comparative review of vertical handover decisionmaking mechanisms in heterogeneous wireless networks. *Indian Journal of Science and Technology*, 8(23), 1-20

Goyal, T., Kaushal, S. (2019). Handover optimization scheme for LTE-Advance networks based on AHP-TOPSIS and Q-learning. *Computer Communications*, *133*, 67-76.

Goyal, P., Lobiyal, D. K., Katti, C. P. (2017). Vertical handoff in heterogeneous wireless networks: A tutorial. In *2017 International Conference on Computing, Communication and Automation (ICCCA)* (pp. 551-566)

Gustafsson, E., Jonsson, A. (2003).Always best connected. *IEEE Wireless communications*, 10(1):49–55.

Hong, K. H., Lee, S. K., Kim, L. Y., Song, P. J. (2009). Cost-based vertical handover decision algorithm for WWAN/WLAN integrated networks. *EURASIP Journal on Wireless Communications and Networking*, *2009*, 1-11.

Kunarak, S., Suleesathira, R. (2020). Multi-criteria vertical handoff decision algorithm for overlaid heterogeneous mobile IP networks. *Journal of the Franklin Institute*, *357*(10), 6321-6351.

Lahby, M., Sekkaki, A. (2017). Optimal vertical handover based on TOPSIS algorithm and utility function in heterogeneous wireless networks. In *2017 International Symposium on Networks, Computers and Communications (ISNCC)* (pp. 1-6). IEEE.

Lal, S., Panwar, D. K. (2007). Coverage analysis of handoff algorithm with adaptive hysteresis margin. In *10th International Conference on Information Technology (ICIT 2007)* (pp. 133-138). IEEE.

Lootsma, F. A. (2013). *Fuzzy logic for planning and decision making* (Vol. 8). Springer Science & Business Media.

Maaloul, S., Afif, M., Tabbane, S. (2013). Vertical handover decision policy based on the end user's perceived quality of service. In *2013 27th International Conference on Advanced Information Networking and Applications Workshops* (pp. 493-498). IEEE.

Márquez-Barja, J., Calafate, C. T., Cano, J. C., Manzoni, P. (2011). An overview of vertical handover techniques: Algorithms, protocols and tools. *Computer communications*, *34*(8), 985-997.

Martinez-Morales, J. D., Pineda-Rico, U., Stevens-Navarro, E. (2010). Performance comparison between madm algorithms for vertical handoff in 4g networks. *In 2010 7th International Conference on Electrical Engineering Computing Science and Automatic Control*, pages 309–314. IEEE.

McNair, J., Zhu, F. (2004). Vertical handoffs in fourth generation multinetwork environments. *IEEE Wireless communications*, 11(3):8–15.

Obayiuwana, E., Falowo, O. E. (2017). Network selection in heterogeneous wireless networks using multi-criteria decision-making algorithms: a review. *Wireless Networks*, *23*(8), 2617-2649.

Saaty, T. L. (2000). *Fundamentals of decision making and priority theory with the analytic hierarchy process* (Vol. 6). RWS publications.

Savitha, K., Chandrasekar, C. (2011). Vertical Handover decision schemes using SAW and WPM for Network selection in Heterogeneous Wireless Networks. *arXiv preprint arXiv:1109.4490*.

Sgora, A., Vergados, D. D. (2009). Handoff prioritization and decision schemes in wireless cellular networks: a survey. *IEEE Communications Surveys & Tutorials*, *11*(4), 57-77.

Sivvam, S., Lakshmi, T. J., Raj, C. D. (2018). Vertical Handoff in Heterogeneous Networks. *International Journal of Pure and Applied Mathematics*, *118*(17), 623-633.

Song, H., Kim, J., Lee, J., Lee, H. S. (2011). Analysis of vertical handover latency for IEEE 802.21-enabled Proxy Mobile IPv6. In *13th International Conference on Advanced Communication Technology (ICACT2011)* (pp. 1059-1063). IEEE.

Srivastava, A., Misra, A. (2016). Exploration of vertical handoff between heterogeneous networks. *Imperial Journal of Interdisciplinary Research*, 2(9):1391–1396.

Takagi, T., Sugeno, M. (1985). Fuzzy identification of systems and its applications to modeling and control. *IEEE transactions on systems, man, and cybernetics*, (1), 116-132.

Tsai, K. L., Liu, H. Y., Liu, Y. W. (2016). Using fuzzy logic to reduce ping-pong handover effects in LTE networks. *Soft Computing*, *20*(5), 1683-1694.

Wang, H. J., Katz, R. H., Giese, J. (1999). Policy-enabled handoffs across heterogeneous wireless networks. In *Proceedings WMCSA'99. Second IEEE Workshop on Mobile Computing Systems and Applications* (pp. 51-60). IEEE.

Wu, S. J. (2011). Fuzzy-based handover decision scheme for next-generation heterogeneous wireless networks. *Journal of Convergence Information Technology*, *6*(4), 285-297.

Yang, S. N., Ke, C. H., Lin, Y. B., Gan, C. H. (2016). Mobility management through access network discovery and selection function for load balancing and power saving in software-defined networking environment. *EURASIP Journal on Wireless Communications and Networking*, *2016*(1), 1-10.

Yoon, K. P., Hwang, C. L. (1995). *Multiple attribute decision making: an introduction*. Sage publications.

Zekri, M., Jouaber, B., Zeghlache, D. (2012). A review on mobility management and vertical handover solutions over heterogeneous wireless networks. *Computer Communications*, 35(17), 2055-2068.

Zhu, F., McNair, J. (2004). Optimizations for vertical handoff decision algorithms. In *2004 IEEE Wireless Communications and Networking Conference (IEEE Cat. No. 04TH8733)* (Vol. 2, pp. 867-872). IEEE.

Zhu, Z., Wakikawa, R., Zhang, L. (2011). A survey of mobility support in the Internet. *IETF Request for Comments*, *6301*.

WEB (a). Access, E. U. T. R. (2015). Requirements for Support of radio resource management (3GPP TS 36.133 version 15.4.0 Release 15), pages 359–361. available at: https://portal.3gpp.org

WEB (b). About Wi-Fi Assist. available at: https://support.apple.com/en-us/HT205296

Received July 5, 2021, revised March 4, 2022, accepted March 18, 2022