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Research Article

A Fuzzy Logic System for Vertical Handover and Maximizing Battery Lifetime in Heterogeneous Wireless Multimedia Networks

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Bandwidth and power hungry applications are proliferating in mobile networks at a rapid pace. However, mobile devices have been suffering from a lack of sufficient battery capacity for the intensive/continuous use of these applications. In addition, the mobile ecosystem is currently heterogeneous and comprises a plethora of networks with different technologies such as LTE, Wi-Fi, and WiMaX. Hence, an issue must be addressed to ensure that quality of experience (QoE) is provided for the users in this scenario: an energy-efficient strategy that is designed to extend the battery lifetime of mobile devices. This paper proposes an architecture which provides an intelligent decision-making support system based on Fuzzy Logic for saving the energy of mobile devices within an integrated LTE and Wi-Fi network. The simulated experiments show the benefits of the solution this architecture can provide by using QoE metrics.

1. Introduction

The increasing demand for new services, technologies, and content is changing the way users obtain access to the Internet. According to Cisco, by 2021, 74% of the mobile devices will generate 98% of the traffic data, and 78% of this will originate from video traffic [1]. The popularization of the use of multimedia applications, together with the increase in the number of mobile users, makes it essential to supply services with a high transmission rate and improved quality.

Both in the current climate and in the future, the wireless network environment will be based on the coexistence of multiple networks that provide access to a wide range of technologies such as Bluetooth, Wi-Fi, WiMAX, and LTE. This will be a place where mobile users, equipped with devices supporting multiple network interfaces, will be able to obtain access to multimedia services through different access networks by means of the radio. In other words, the heterogeneity of a wireless environment provides the opportunity to assess and select the best network from a range of others, on the basis of the required conditions of a multimedia service.

In light of this, handover is a procedure that allows a mobile device to be disconnected from a network so that it can be connected to another. Its goal is to allow mobile users to be always connected (ABC, Always Best Connected [2]) to a network, so that their application can keep operating while they are relocating between different places. When the decoupling and connection involve the same network technologies, the phenomenon is called horizontal handover, whereas vertical handover involves the use of different technologies.

Since users want a better multimedia experience in their mobile devices, the delivery of video of a high quality is a more challenging task in wired networks. This is also owing to restrictions and mobility behavior and the environment of heterogeneous wireless networks itself; however, it mainly lies in the challenge of meeting the required conditions for multimedia applications with regard to the transfer of data and ensuring low latency and an insignificant loss.

The decision of when and where to carry out the handover will depend on several factors or attributes such as the following: QoS (Quality of Service), RSS (Received Signal Strength), bandwidth, the battery consumption rate, and mobile user speed. The concept of Quality of Experience (QoE) is becoming a key factor because it can measure the degree of quality of a multimedia service through the perception of the user. In other words, the satisfaction of the user can be measured through required conditions based on social psychology, cognitive science, and engineering science [3].

Expectations about satisfaction for different services and application vary among different users. The traditional concept of QoS fails to take account of the fact that the satisfactions of the user should be used as an indicator, or, rather, it is only concerned with the network properties through metrics designed for the delivery of content [14–16]. This means that QoE should be an important attribute to take into account in the handover decision-making process.

Another key factor that needs to be considered is the level of power consumption of the mobile device, since video applications consume a large amount of energy. Today, energy saving is a concern that must be addressed, particularly in heterogeneous wireless networks which provide a wide range of opportunities to choose networks that allow improved energy saving through vertical handover. However, it is a real challenge to select an ideal network that takes account of the users' preferences and is, at the same time, energy efficient.

The different types of technology have different bandwidth as well as different power consumption. Therefore, there is a need for a balance between bandwidth and energy consumption, because there will be times when the user opts for a network with more bandwidth, reducing the battery life, as there will be times when the user will choose to migrate to a network with less bandwidth but with a longer battery life [17, 18]. For this reason, the Fuzzy System will have as one of its inputs the battery consumption.

This paper creates an algorithm for vertical handover decision-making based on fuzzy logic and which takes account of the following when selecting the best network: QoE criteria, energy consumption and the mobility of the user.

The paper is structured in the following way: The Section 2 provides a brief overview of studies related to vertical handover; The Section 3 describes the architecture of the fuzzy logic system for heterogeneous wireless networks; The Section 4 provides the analysis of the results and the Section 5 summarizes the conclusion of the study and makes suggestions for further research in the field.

2. Related Works

This section provides an overview of several related works on heterogeneous architectures that provide QoE support, together with seamless mobility for mobile users of different technologies or energy-saving strategies for battery devices.

There are several researches in the literature such as [4] that proposes a handover mechanism based on the coordination between MIH (Media-Independent Handover) and PMIPv6 (Proxy Mobile IPV6) to support user mobility. The main focus of the research was the reduction of failed handovers, packet loss, and QoS requirements. However, the proposal does not consider support for energy saving and QoE. The work [5] proposes an algorithm that uses the parameters Time-to-Trigger (TTT) and Hysteresis Margin. Such parameters offered improvements in energy efficiency and Ping Pong Handover Ratio system. However, the proposal itself does not take into consideration the quality of user experience in its mechanism.

The Proposals [6, 7] Decision mechanisms use strategies based on Multiple Attributes Decision-Making (MADM). The proposal [6] developed a handover decision algorithm with energy efficiency support based on the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), which has the function of offering a rank of alternatives on the best networks for the selection. This algorithm uses as parameters power consumption, traffic class, and battery level of each network interface of the mobile device. The work of [7] presents a comparison of different MADM methods, considering the battery level standard. The main methods evaluated were AHP (The Analytic Hierarchy Process), ANP (Analytical Network Process), Fuzzy AHP, and Fuzzy ANP, where such methods were combined in 120 combinations for evaluation, in which the research results conclude that the best methods of combinations were Euclidian-normalization-TOPSIS-FANP and Sum normalization-GRA-FANP. However, the proposals [6, 7], even considering the energy consumption, could not enable a relation with the standard of QoE.

The paper [8] proposes the use of the fuzzy system to handover decision, and the strategy was the combination of QoS parameters and QoE (Mean Opinion Score) indicators. The proposal [9] uses the QoE to select the best connection; the QoE was evaluated using Mean Opinion Score (MOS) in real time, through the PSQA (Pseudosubjective Quality Assessment) technique based on statistical learning through RNN (Random Neural Network). In [10] a Software-Defined Networking (SDN) architecture was proposed to implement a handover decision strategy based on fuzzy system considering QoS and QoE requirements; the fuzzy system is able to monitor a set of APs (Access Points) for the selection of the best AP to the user. In [11], the proposal is a multicriteria algorithm combining fuzzy system and utility function as a decision strategy. The proposal uses the fuzzy system to support the input imprecision information, while the utility function is responsible for reducing the number of handovers. The papers [8, 10], though proposing improvements to QoE, do not provide support for energy consumption. Although the proposal [11] considers multiple criteria such as delay, available bandwidth, and received signal strength, however the QoE and power consumption were not considered.

In [12], we proposed the vertical handover decision algorithm, Artificial Neural Networks (ANN), which uses a learning method based on neural network. The algorithm considers the parameters of QoE and QoS in its decision mechanism but does not have support in relation to the user satisfaction. Despite the collected results, the ANN obtained a reduced number of handoffs performed, as well as the reduction of the delays. The proposal [13] uses a QoE evaluation

Table 1: Related Works.

Proposal	QoE	Energy Efficiency	Decision Strategy	Proposal Focus
[4]	No	No	Coordination between MIH and PMIPv6	Reduce number of Ping Pong events and handover failures
[5]	No	Yes	Time-to-Trigger (TTT) and Hysteresis Margin	Improve energy efficiency and Reduce Ping Pong Handover Ratio
[6]	No	Yes	MADM - TOPSIS	Reduce power consumption
[7]	No	Yes	MADM - Euclidian-normalization-TOPSIS-FANP and Sum normalization-GRA-FANP	Support for reducing energy consumption
[8]	Yes	No	Fuzzy Logic System	Selection of the best network using QoE
[9]	Yes	No	RNN (Random Neural Network)	Selection of the best network using QoE
[10]	Yes	No	SDN and Fuzzy Logic System	QoS and QoE support
[11]	No	No	Fuzzy Logic System and Utility Function	Reduction in the number of handoffs
[12]	Yes	No	Artificial Neural Networks (ANN)	Reduction in the number of handoffs and delay
[13]	Yes	Yes	RNN (Random Neural Network)	Correlation between QoE and QoS in heterogeneous networks
Current Proposal	Yes	Yes	Fuzzy Logic System	Selecting the best network considering trade-off between QoE and energy efficiency

mechanism based on RNN in order to search the mapping relationship between QoS values and MOS (Mean Opinion Score) values. In addition, a QoE-Q was proposed as a vertical handover algorithm, considering Q-learning theory, to maximize user experience quality. Simulation results point to an increase in QoE performance as well as improvements in mobile device energy consumption. However, the proposal has, as main focus, a vertical handover mechanism based on the correlation between QoE and QoS in heterogeneous networks.

Therefore, none of them provides a joint approach that involves a solution for both energy-saving and vertical handover with QoE support. The proposal of this article is to propose a handover decision mechanism which provides the choice of the network taking into consideration the trade-off between energy consumption and QoE. Table 1 compares the related works in relation to the current proposal.

3. A Fuzzy Logic System for a Heterogeneous Wireless Network Architecture with an Energy-Efficiency Support System

This section presents a proposal with a Fuzzy System for seamless handover and energy-efficient support for mobile multimedia communication. The objective of the proposed architecture is to save battery in heterogeneous environment networks with multiple devices as expected for Future Internet environments (see Figure 1).

3.1. Problem Statement and Major Contributions. One of the main contributions made by this article is to examine a dynamic heterogeneous architecture composed of an LTE technology (which is currently being adopted as the standard for 4G networks) and also formed of the IEEE 802.11n technology. This dynamic heterogeneous architecture is mobile-oriented to Future Internet environments since it will offer multiple connectivity options and allow the user to choose the best network for a particular period of time. Even if the user moves away from his starting place to a new destination point, the architecture will continue to offer multiple connectivity options.

When the mobile device is within the area of coverage of two or more networks, it has to select the network to which it will be connected, although the devices do not have any kind of mobile support or intelligence that can assist in its decision-making. Not even the technology standards can provide any kind of support for making decisions with regard to the selection and connection of the network.

At first, the only adopted criterion is the RSSI, or, in other words, the mobile device will only be connected to the nearest access point or base station. As a result, the lack of support for decision-making when selecting the network can cause the user problems since a mobile device with low battery

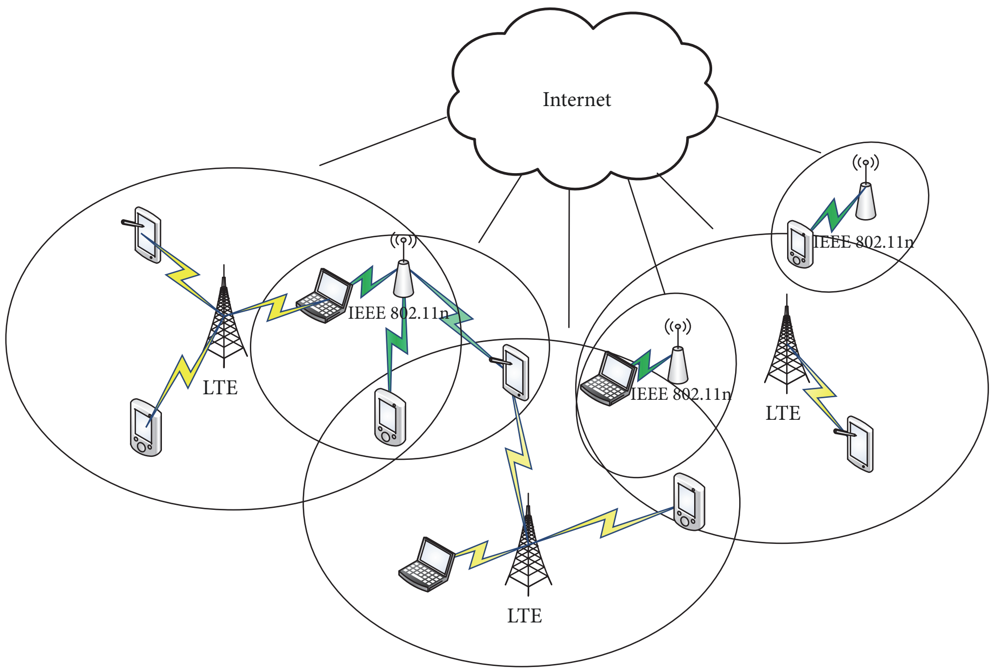

Figure 1: A Heterogeneous Wireless System Network.

power might be connected to a network which increases its energy consumption and hence reduces its battery life. Similarly, a user with a battery that has a prolonged life might be connected to a network that is saturated and offers a low bandwidth, and this can damage the user's application.

User mobility can also impair the quality of experience since users with high mobility can carry out excessive and unnecessary handovers, as in the case of the ping-pong handover. This means a mobile device will be connected to a new network even though it will only remain within the area of coverage of this new network for a short time, on account of its high mobility; this means that it will have to reestablish connection with the point of contact or previous base station.

Owing to the lack of mobile support or intelligence in the devices, another contribution made by this article is the Fuzzy Logic System which is oriented to heterogeneous wireless environments to assist decision-making with regard to the selection and connection of the network. However, the technologies must have different features before they can become a heterogeneous environment and, for this reason, this article puts forward a Fuzzy Logic System with two sets of rules. If the newly detected network is a Wi-Fi network, the Fuzzy system will be governed by a set of rules designed for this technology, whereas if the newly detected network is an LTE network, the Fuzzy system will also be governed by a set of rules designed for this technology.

The Fuzzy Logic System that is guided by two sets of rules that are applicable to each technology will allow the rational use of the mobile device. This system will prevent a mobile device with low energy from being connected to a network with high energy consumption and thus reduce the battery life. Similarly, the Fuzzy Logic System will prevent a device with a high battery capacity from being connected to a network that is saturated and hence has a low bandwidth; in this way, the Fuzzy System can also carry out load balancing by distributing the mobile devices among the networks. In addition, the Fuzzy System will be able to prevent high-mobility devices from being either rapidly connected to the network or disconnected and hence avoid the ping pong handover. For this reason, Fuzzy is unlike traditional systems, since it was implemented with particular technological features in mind and incorporates three input variables: mobility, battery level and Quality of Experience.

The technologies have different battery consumption and this needs to be taken into account; for this reason, this article makes another contribution which is the use of a realistic battery model that has specific battery discharge parameters for each technology. The Wi-Fi and LTE technologies have different battery levels and as well as this, each mobile device status also has a different level of battery consumption. This is because the battery discharge rate of a mobile device which is transmitting messages is different from when it is receiving them and in addition, is different when the mobile device is idle. This explains why the battery model used in the Simulator was Rakhmatov–Vrudhula, since the model traditionally used in the simulators is the linear model which has a single battery discharge rate regardless of its technology or status.

Another contribution made by this article is the use of Quality of Experience as an input metric of the Fuzzy Logic System. A measurement algorithm that could be used for Quality of Experience was implemented in the base stations and access points. The mobile device provides information (by means of network signaling messages) to the base station and access point to which it is connected, together with the level of quality of experience being offered. This measurement is derived from the number of video packets received by the mobile device, and this number allows the level of QoE being offered, to be classified.

3.2. The Fuzzy Rules Architecture. Fuzzy logic is an extension of conventional logic (binary). Unlike traditional logic that works with exact values, fuzzy logic allows a degree of uncertainty, by seeking to manipulate imprecise terms that are normal in human language. This enables a digital system to be designed, which only works with binary logic, can mimic human thought and is able to process information in a subjective way.

In a fuzzy system, the result appears in a range from 0 to1. The value 0 means complete exclusion and a value 1 means full membership. The other values represent intermediate degrees of relevance. A certain element may also belong to two or more fuzzy sets that are defined in the same universe, where the values of the membership functions for each fuzzy set may be different. Thus, an element can belong more to one fuzzy set and less to others.

The Fuzzy sets are usually defined in linguistic terms Where the values represent the height of an individual, there may be three fuzzy sets that are defined as follows: low, medium, and high. If, for example, there are five fuzzy sets in the universe, one possibility would be as follows: very low, low, medium, high, and very high.

In this paper, three metrics were chosen as input: mobile speed, the remaining battery power and QoE (Quality of Experience). These metrics are used for the dynamic operations during the simulations. Mobile speed is also a very important metric, since a user with a high speed can be degraded if handover is performed within a small coverage area of the network. The QoE value indicates the video quality of a link network with a current Base Station/Access Point and it is an important metric to trigger the handover. The battery consumption varies depending on which network is selected, and there will be situations when the selected network should not only take into account the QoS/QoE requirements, but also the remaining degree of energy of the device.

It was decided to divide the speed (m/s), into three sets: low speed (interval [0 to 6]), medium speed (interval [4 to 14]), and high speed (when the speed is higher than 12m/s). Three sets were also defined for the QoE (dB): Low (interval [0 25], medium (interval [22 31] and high (when the QoE is higher than 31dB]. The battery power (in percentage terms) is defined in three sets: Low [0%–25%], medium [20%-80%], high [more than 70%]. These three fuzzy sets generate four outputs: NOT to make handover, PROBABLY NOT to make handover, PROBABLY YES to make handover and YES to make handover (see Figure 2).

The architecture consists of two technologies: Wi-Fi (the IEEE 802.11n) and 4G (the LTE); the Fuzzy System will receive the necessary information to decide what is the best connection for that moment. Precisely because the architecture is behaved by two technologies, the Fuzzy System has two sets of specific rules for each one that will be explained below.

The Fuzzy Rules determine when the mobile user will change the network (handover). When the mobile user is connected to a Wi-Fi network and detects a new LTE network, the Fuzzy System will trigger the handover in the situations (Table 2):

Table 2: Wi-Fi Rules.

Speed	QoE	Energy	Handover
Low	Medium	Medium	ProbablyYes
Low	Medium	High	ProbablyYes
Medium	Medium	Medium	ProbablyYes
Medium	Medium	High	ProbablyYes
Low	Low	High	Yes
Low	High	Low	Yes
Medium	Low	Low	Yes
Medium	Low	Medium	Yes
Medium	Low	High	Yes
Medium	Medium	Low	Yes
Medium	High	Low	Yes
High	Low	Low	Yes
High	Low	Medium	Yes
High	Low	High	Yes
High	Medium	Low	Yes

In general, a mobile user connected to the Wi-Fi network will change to an LTE network when in Wi-Fi network the QoE is Low, or the energy level is medium/high and it has a high speed. This situation prioritizes the quality of experience for the mobile users.

When the mobile user is connected to an LTE network and detects a new Wi-Fi network, the Fuzzy System will trigger the handover in the situations (Table 3).

Table 3: LTE Rules.

Speed	QoE	Energy	Handover
Low	Medium	Medium	ProbablyYes
Low	Medium	High	ProbablyYes
Medium	Medium	Medium	ProbablyYes
Medium	Medium	High	ProbablyYes
Low	Low	Low	Yes
Low	Low	Medium	Yes
Low	Low	High	Yes
Low	Medium	Low	Yes
Low	High	Low	Yes
Medium	Low	Low	Yes
Medium	Low	Medium	Yes
Medium	Low	High	Yes
Medium	Medium	Low	Yes
Medium	High	Low	Yes
High	Low	Low	Yes
High	Low	Medium	Yes
High	Low	High	Yes
High	Medium	Low	Yes

In general, a mobile user connected to the LTE network will change to a Wi-Fi network when in LTE network the QoE

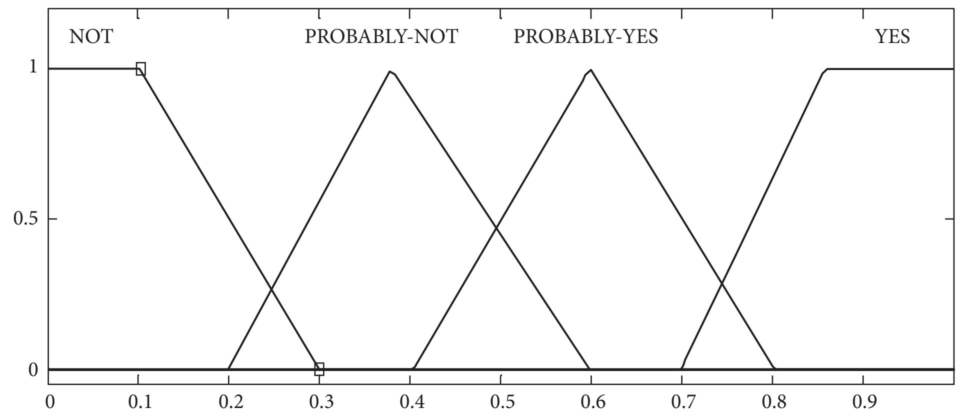

Figure 2: Output Fuzzy System.

is Low, or energy level is low/medium and it has a low speed. This situation prioritizes the energy level for the mobile users.

3.3. The Rakhmatov–Vrudhula Model. The purpose of a mathematical model for batteries is to study/predict their performance or behavior. A battery is an assembly of electrochemical cells, each of which consists of two electrodes: one with negative polarity nodes and a cathode which has positive polarity. The electrochemical reactions generate electrons that are released to provide electric power to the devices causing the battery drain [19], the battery model used in this paper was Rakhmatov–Vrudhula model.

The Rakhmatov–Vrudhula battery model [19] is more realistic than the linear model because it takes account of the transmission states, and for each state there is a different type of electric discharge (see (1)). This model includes different battery capacity and rates of recovery (in idle mode it is possible to increase the lifetime of the battery) for different types of batteries (alkaline, lithium ions).

$$\alpha = \sum_{k=1}^{n} 2I_{k-1} A\left(L, t_k, t_{k-1}, \beta\right) \quad (1)$$

where, I_{k-1} = the current discharge during the period $k-1$, A = calculates the discharge rate of the non-linear battery model, L = battery lifetime, t_k= duration time of k period, and t_{k-1}= duration time of k – 1 period.

3.4. The Distributed Mobility Management (DMM) Scheme. In the application scenario, the handover decision-making is shared between the mobile station and point of attachments (POA) (e node B or access point). The Figure 3 illustrates the vertical handover process between the current and the target network in the proposed network architecture.

(1) When the MS detects a targeted neighbor network, it sends a *Link_Detected* message to the target network, and this message allows the targeted network to recognize the mobile station. (2) The targeted network replies with a *Link_Parameters_Report* message, which contains network information, such as RSSI and the level of Quality of Experience being offered by the new network. (3) The MS passes the energy, the QoE and mobility information to the Fuzzy System (Wi-Fi or LTE rules on the network detected). The fuzzy output states whether the handover is necessary or not, the decision is made based on the value of output inference, the network that presents the highest value of inference will be the one chosen by the mobile device. (4) After the Fuzzy decision, the MS sends a *Handover_Initiate* message to the targeted network to trigger the vertical handover. (5) The MS sends the current network a *Link_Down* message about the need to change to a new network.

4. Evaluation of the Architecture

This section evaluates the architecture designed to provide QoE with maximized battery power. The performance assessment was carried out through Network Simulator 2 (NS2) and Evalvid Tool (to transmit the video in the simulation) [20]. The objective is to demonstrate the benefits of the proposed architecture in relation to the original architecture, as well as to compare the performance of the proposal with other papers researched in the literature. The proposal has been compared in relation to papers [8–11]. The proposals [8–11] were adapted for the NS-2 simulator to the performance comparison. The mobility model used was Random Way Point, so the movements and speed of the mobile users were random in the simulation.

The video used in this simulation was “Sintel”, which consists of 1253 frames with the YUV format, sampling 4:2:0 and dimensions of 1080x720, which was compressed through a MPEG-4 CODEC and sent at a 30 frame/s rate [21]. The video was chosen because the “Sintel” video is high definition.

The simulated parameters that were configured for all the experiments, are shown in Table 4 and represent the normal values of IEEE 802.11n and LTE networks.

The simulation parameters for the evaluation of energy consumption are described in Table 5. The initial battery voltage was 1000 joules and different power transmission and reception charges were adopted for each technological system. In the case of Wi-Fi technology, the same values were adopted as in [21] and the values used in [22] for LTE.

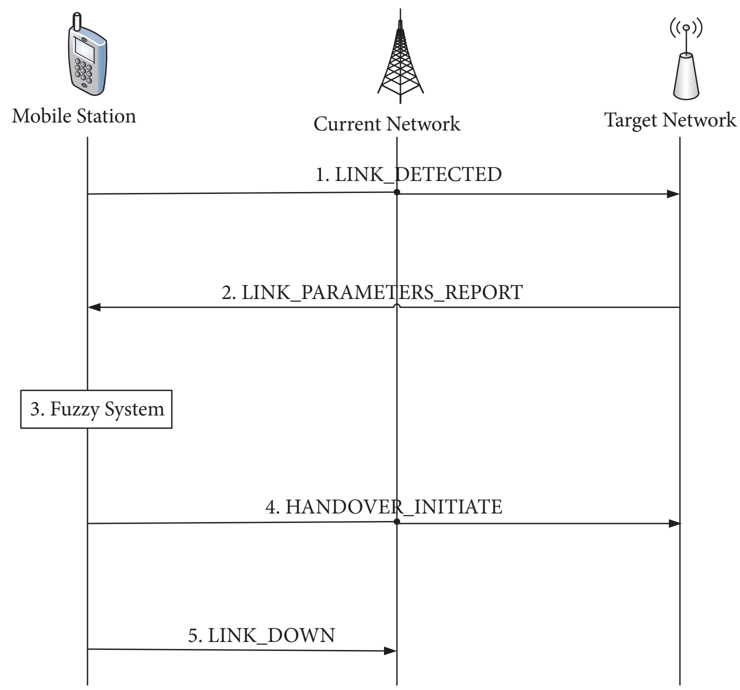

Figure 3: Handover signaling.

Table 4: Simulated Parameters.

	IEEE 802.11n	LTE
Rate transmission	108 Mbps	150 Mbps
Coverage area	100 m	1000 m
Videos	Resolution: 176 x 144 CIF Resolution: 352 x 288 CIF Resolution: 1080 x 720 CIF Frames rate: 30 frames/s Colour Mode: Y, U, V	
Queue	Drop Tail (40 ms delay)	
Packet size	1052 bytes	
Maximum Fragmentation packet	1024 bytes	
Number of simulations	50	
Confidence interval	95 %	
Number of videos	3	

Table 5: Energy Simulated Parameters.

	Transmission (W)	Reception (W)
WiFi	1.3	0.9
LTE	2.5	1.7

4.1. The Power Consumption Results. Initially, the results were used to compare the battery life when the mobile user is connected in the architecture without Fuzzy System (the architecture with original protocols) with the mobile user connected in the architecture with Fuzzy System, during the simulations the mobile user performs handovers.

The mobile user in the architecture without Fuzzy System (Original Architecture) was connected for approximately 47 minutes, in the paper [11] was 48,5 minutes, in the paper [10] was 50,3 minutes, in the paper [9] was 51,2 minutes, in the paper [8] was 52 minutes and while the mobile user with an energy-saving policy was connected for 58 minutes (Figure 4). There is a gain in energy because with the Fuzzy System the handover in the network takes place when the battery level of the device is low. In this case, there will be a loss in quality for the user but an increase in the lifetime of the battery.

4.2. QoS Results. This paper assesses the benefits of the scheme in terms of the network throughput rate. In the first situation, the mobile device was within the intersection of areas of coverage, while in the simulation in the original architecture without the Fuzzy Logic System, in the papers [8–11], the mobile device chose the network that was nearest even though it was saturated and offered a low quality of service. However, in the simulation in the architecture with the fuzzy system, the mobile device chose the network that offered the best quality of service. In Graph (Figure 5), it can be seen that the network throughput rate in the architecture with the fuzzy system was superior. The average throughput rate in the original architecture was 0,51 Mbps, in the paper [11] was 0,65Mpbs, in the paper [10] was 0,76Mbps, in the paper [9] was 1,6 Mbps, in the paper [8] was 1,8 Mbps and while in the architecture with the fuzzy system the average throughput rate was 2,23 Mbps.

In the second situation, the simulations had mobile devices with high mobility within the coverage area of the networks. In a scenario where the original architecture, the

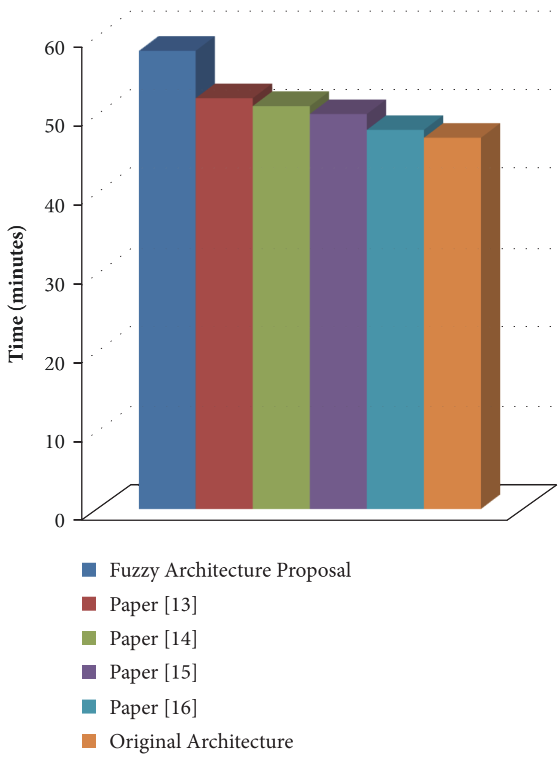

Figure 4: Energy-Saving over time.

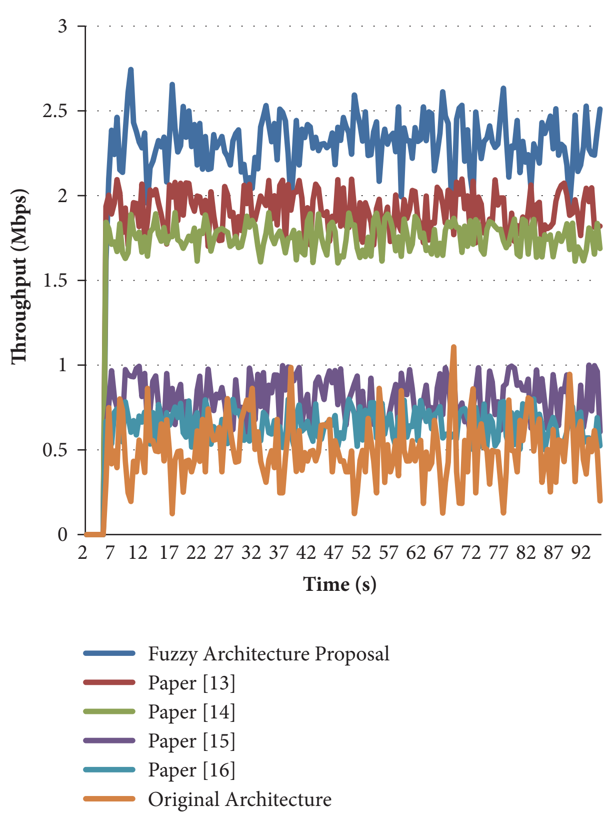

Figure 5: Throughput over Time.

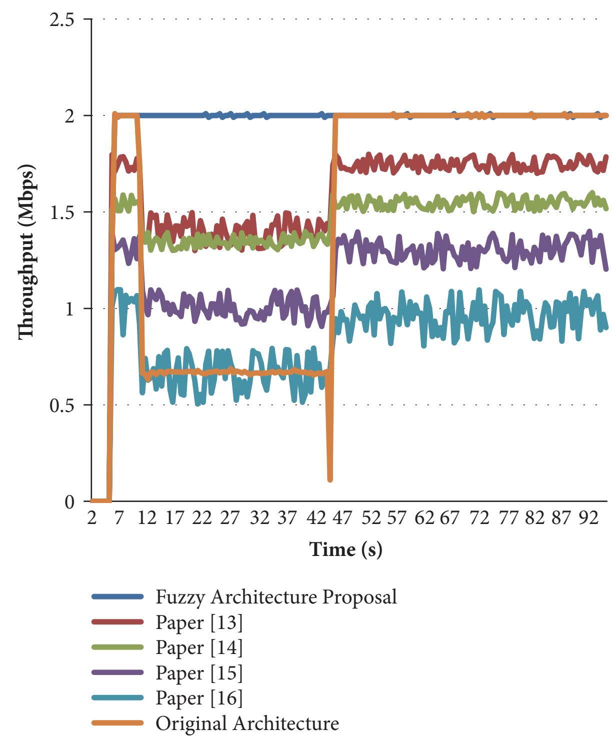

Figure 6: Throughput in ping-pong handover situation.

papers [8–11] had no mobile support for the selection of a network, the high-mobility devices carried out the ping-pong handover. In other words, they were connected to a new network, (which was offering less bandwidth) and were later connected again to their previous network. This unnecessary exchange of network impaired the customer flow rate and for this reason, in a situation where the architecture has a fuzzy logic system, the high-mobility mobile devices failed to carry out the ping-pong handover or maintain its quality of service. In Graph (Figure 6), it can be noted that there is a loss of flow in the high-mobility mobile devices which carried out the ping-pong handover.

4.3. QoE Results. This paper also analyses the simulations with a video application. The video results are evaluated by means of objective QoE metrics: (i) Peak Signal to Noise Radio (PSNR), (ii) Structural Similarity Metric (SSIM) and (iii) Video Quality Metric (VQM). The data are collected by using the MSU Video Quality Measurement Tool (VQMT). The PSNR is a traditional objective method to estimate the standards of multimedia services based on the opinions of the user. The SSIM index is a decimal value between 0 and 1, where 0 means there is a zero correlation with the original image, and 1 means exactly the same image. The VQM determines the level of multimedia quality based on human eye perception and subjective factors, including blurring, global noise, block distortion and colour distortion. The results of the VQM estimates range from values of 0 to 5, where 0 is the best possible score. In accordance with the network parameters, the Fuzzy system will keep the user longer in the network that offers the best quality.

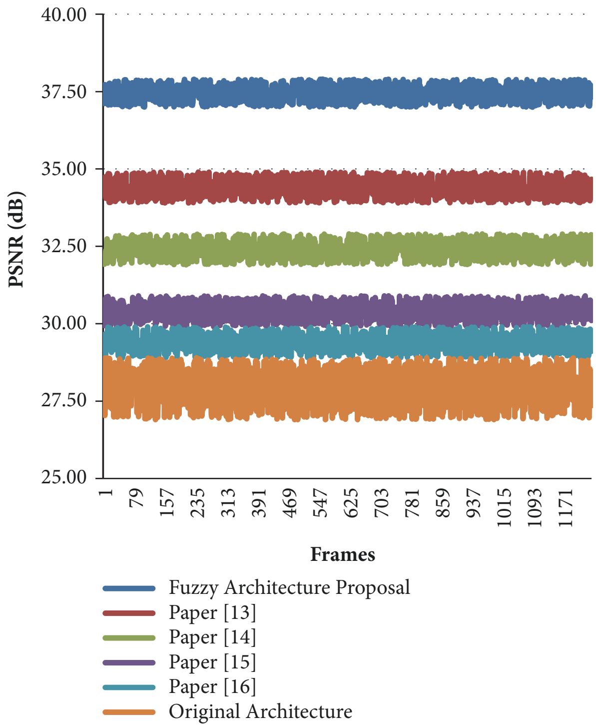

Figure 7: PSNR over Frames.

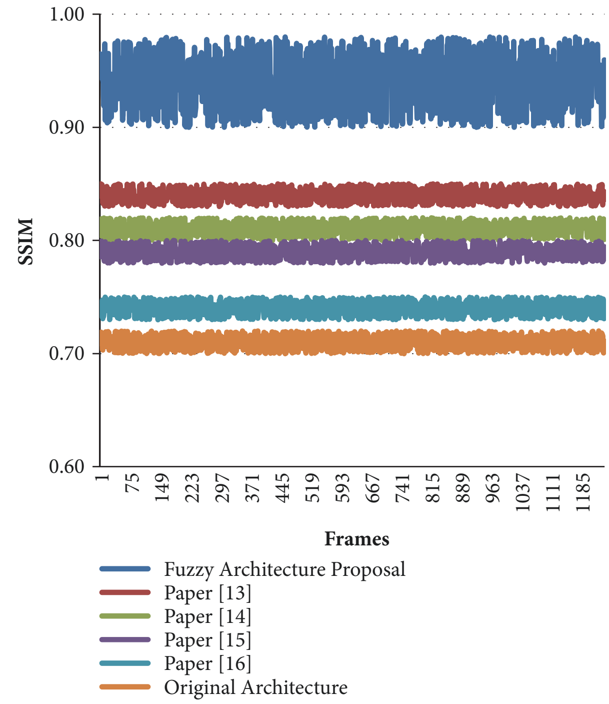

Figure 8: SSIM over Frames.

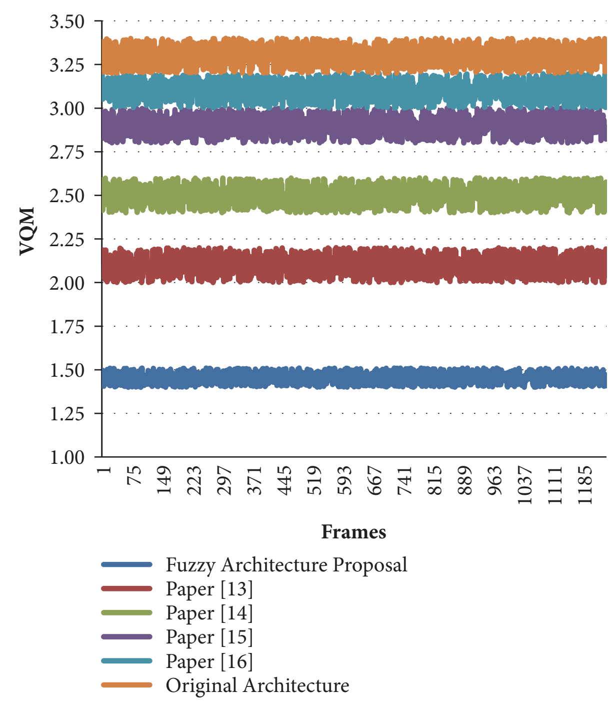

Figure 9: VQM over Frames.

The videos transmitted with the Fuzzy System were superior to those transmitted without the Fuzzy System, to the papers [8–11]. The PSNR value for a video without the Fuzzy System was 28dB which can be rated as a fair video, the PSNR value for video in paper [11] was 29dB and rated as fair video, the PSNR value for video in paper [10] was 30dB which can be rated as a fair video, the PSNR value for video in paper [9] was 32dB and rated as good video, the PSNR value for video in paper [8] was 34dB which can be rated as a good video, whereas the PSNR value for the video with the Fuzzy System was 37dB and rated as an excellent video. The video transmitted with the fuzzy system had a better performance during the transmission and kept a balance between energy and QoE (see Figure 7).

The SSIM value for a video without the Fuzzy System was 0. 71, the SSIM value for video in paper [11] was 0,73, the SSIM value for video in paper [10] was 0,79, the SSIM value for video in paper [9] was 0,81, the SSIM value for video in paper [11] was 0,85 and while the SSIM value for the video with the Fuzzy System was 0. 93 (see Figure 8).

The VQM value for a video without the Fuzzy System was 3.95, the VQM value for video in paper [11] was 3,02, the VQM value for video in paper [10] was 2,8, the VQM value for video in paper [9] was 2,41, the VQM value for video in paper [8] was 2,1 and the VQM value for the video with Fuzzy System was 1.44 (see Figure 9).

Figure 10 shows that the video transmitted with the Fuzzy System had a better performance, since the delay was less than the video transmitted without the Fuzzy System, in the papers [8–11]. The lower the delay, the faster and more efficient the delivery of the frames, which confirms the superiority of the video transmitted with the fuzzy scheme by means of the QoE metrics (Figure 10).

The superiority of the video transmitted with the Fuzzy System can also be determined by making a visual comparison of the frame transmitted with the mechanism (Figure 16), and with a frame of the video transmitted without the

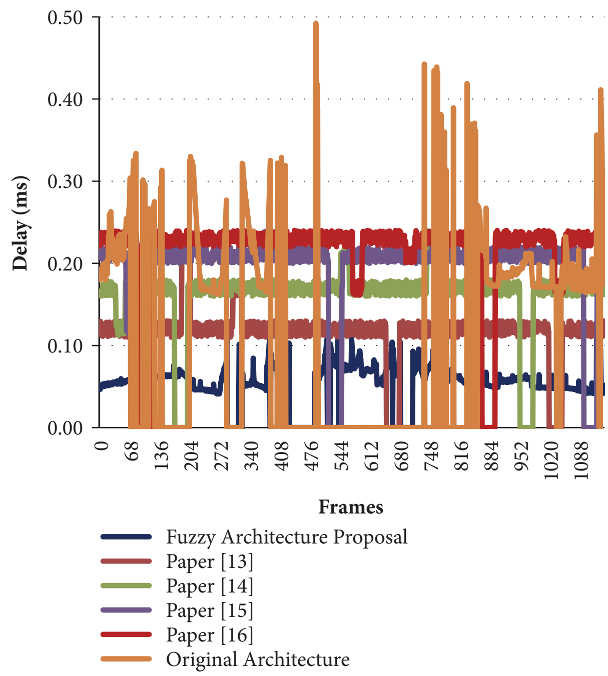

Figure 10: Delay over Frames.

Figure 11: Without the Fuzzy System.

mechanism (Figure 11), in the paper [11] (Figure 12), in the paper [10] (Figure 13), in the paper [9] (Figure 14), in the paper [8] (Figure 15).

5. Conclusion and Suggestions for Future Work

The mobile devices for the new heterogeneous wireless communication architecture need to be connected to networks that are able to provide the best quality of experience. However, there are occasions when it is important is to save energy and extend the battery life, even if this reduces the quality, to ensure continuity and avoid an abrupt termination of the services. This paper proposes a Heterogeneous Wireless System formed of IEEE 802.11n and LTE networks that makes use of Fuzzy Rules to support an energy-efficient approach for saving battery power, while keeping QoE at satisfactory levels. Simulation evaluations show the benefits of this intelligent-based middleware solution for energy-efficient seamless vertical handover.

In future studies, the architecture will include new technologies, inputs for the Fuzzy Systems, and battery models, as well as dynamic scenarios with mobile users competing in IEEE 802.11n and LTE networks.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Figure 12: In the Paper [11].

Figure 13: In the Paper [10].

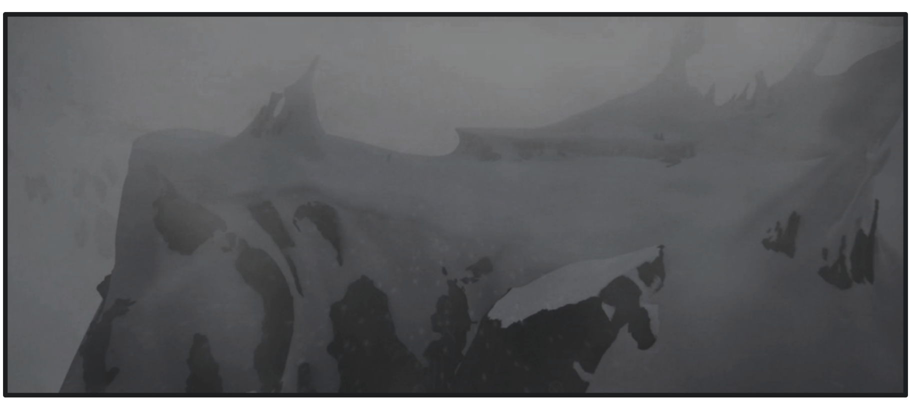

Figure 14: In the Paper [9].

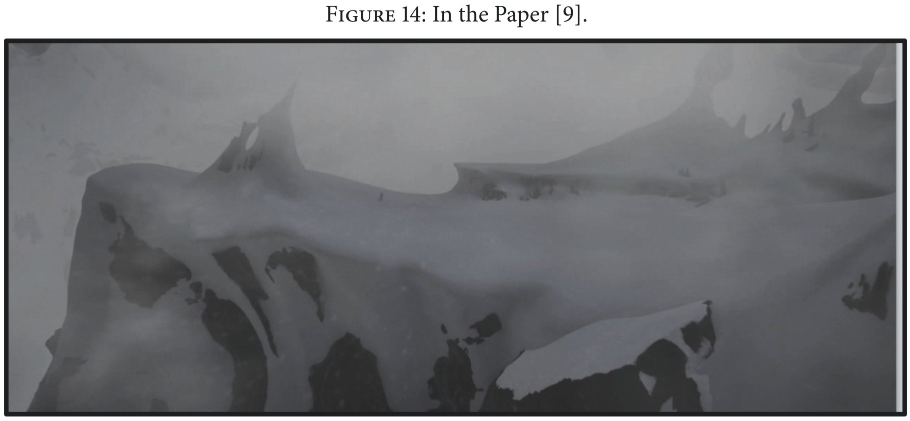

Figure 15: In the Paper [8].

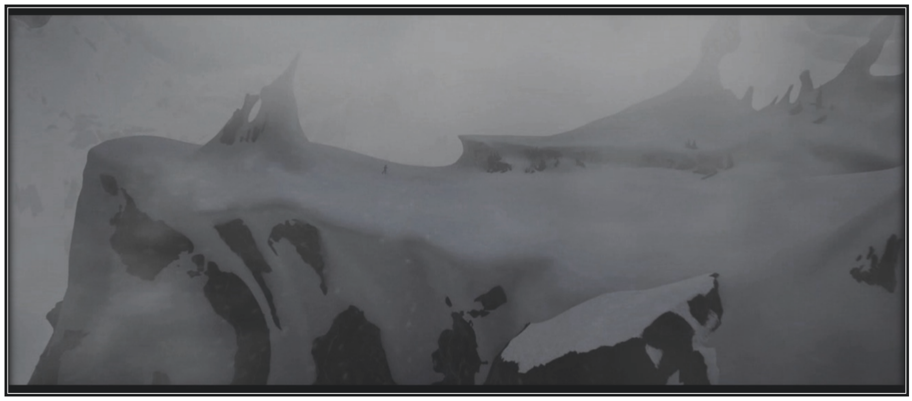

Figure 16: With the Fuzzy System.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] CISCO, "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2016-2021," white paper, available online: https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/complete-white-paper-c11-481360.pdf (accessed 28.03.2018).

[2] E. Gustafsson and A. Jonsson, "Always best connected," *IEEE Wireless Communications Magazine*, vol. 10, no. 1, pp. 49–55, 2003.

[3] L. Zou, R. Trestian, and G.-M. Muntean, "E3DOAS: Balancing QoE and Energy-Saving for Multi-Device Adaptation in Future Mobile Wireless Video Delivery," *IEEE Transactions on Broadcasting*, vol. 64, no. 1, pp. 26–40, 2018.

[4] A. A. Mansour, N. Enneya, and M. Ouadou, "A velocity-aware handover trigger in two-tier heterogeneous networks," *Future Internet*, vol. 10, no. 1, 2018.

[5] B. Zhang, W. Qi, and J. Zhang, "An energy efficiency and ping-pong handover ratio optimization in two-tier heterogeneous networks," in *Proceedings of the 2018 IEEE 8th Annual Computing and Communication Workshop and Conference (CCWC)*, pp. 532–536, Las Vegas, Nev, USA, January 2018.

[6] R. Priyanka, S. Baghla, and M. Himanshu, "Energy Efficient Network Selection in Heterogeneous Network using TOPSIS".

[7] M. Mansouri and C. Leghris, "A battery level aware MADM combination for the vertical handover decision making," in *Proceedings of the 13th IEEE International Wireless Communications and Mobile Computing Conference, IWCMC 2017*, pp. 1448–1452, Spain, June 2017.

[8] A. B. Zineb, M. Ayadi, and S. Tabbane, "QoE-fuzzy VHO approach for heterogeneous wireless networks (HWNs)," in *Proceedings of the 30th IEEE International Conference on Advanced Information Networking and Applications, AINA 2016*, pp. 949–956, Switzerland, March 2016.

[9] K. Piamrat, A. Ksentini, C. Viho, and J.-M. Bonnin, "QoE-aware vertical handover in wireless heterogeneous networks," in *Proceedings of the 7th International Wireless Communications and Mobile Computing Conference (IWCMC '11)*, pp. 95–100, Istanbul, Turkey, July 2011.

[10] O. Aldhaibani, F. Bouhafs, M. Makay, and A. Raschella, "An SDN-Based Architecture for Smart Handover to Improve QoE in IEEE 802.11 WLANs," in *Proceedings of the 2018 32nd International Conference on Advanced Information Networking and Applications Workshops (WAINA)*, pp. 287–292, Krakow, Poland, May 2018.

[11] A. Kammoun and N. Tabbane, "Fuzzy utility decisional vertical handover algorithm for enhancing network performances," in *Proceedings of the 5th International Conference on Multimedia Computing and Systems, ICMCS 2016*, pp. 337–343, Marrakech, Morocco, October 2016.

[12] A. B. Zineb, M. Ayadi, and S. Tabbane, "QoE-based vertical handover decision management for cognitive networks using ANN," in *Proceedings of the 2017 Sixth International Conference on Communications and Networking (ComNet)*, pp. 1–7, Hammamet, March 2017.

[13] J. Chen, Y. Wang, Y. Li, and E. Wang, "QoE-Aware Intelligent Vertical Handoff Scheme Over Heterogeneous Wireless Access Networks," *IEEE Access*, vol. 6, pp. 38285–38293, 2018.

[14] Y. Xu, R. Q. Hu, L. Wei, and G. Wu, "QoE-aware mobile association and resource allocation over wireless heterogeneous networks," in *Proceedings of the 2014 IEEE Global Communications Conference, GLOBECOM 2014*, pp. 4695–4701, USA, December 2014.

[15] I. V. S. Brito and G. B. Figueiredo, "Improving QoS and QoE Through Seamless Handoff in Software-Defined IEEE 802.11 Mesh Networks," *IEEE Communications Letters*, vol. 21, no. 11, pp. 2484–2487, 2017.

[16] L. Yala, P. A. Frangoudis, and A. Ksentini, "QoE-aware computing resource allocation for CDN-as-a-service provision," in *Proceedings of the 59th IEEE Global Communications Conference, GLOBECOM 2016*, USA, December 2016.

[17] M. F. Tuysuz, "An energy-efficient QoS-based network selection scheme over heterogeneous WLAN - 3G networks," *Computer Networks*, vol. 75, pp. 113–133, 2014.

[18] M. F. Tuysuz and R. Trestian, "Energy-Efficient Vertical Handover Parameters, Classification and Solutions over Wireless Heterogeneous Networks: A Comprehensive Survey," *Wireless Personal Communications*, vol. 97, no. 1, pp. 1155–1184, 2017.

[19] D. N. Rakhmatov and S. B. K. Vrudhula, "An analytical high-level battery model for use in energy management of portable

electronic systems," in *Proceedings of the International Conference on Computer-Aided Design 2001*, pp. 488–493, USA, November 2001.

[20] "Evalvid," http://www.tkn.tu-berlin.de/research/evalvid/, 2018.

[21] L. Marie and M. Nilsson, "Investigating the energy consumption of a wireless network interface in an ad hoc networking environment," in *Proceedings of the 20th Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM '01)*, vol. 3, pp. 1548–1557, Anchorage, Alaska, USA, April 2001.

[22] M. Deruyck, W. Vereecken, E. Tanghe et al., "Comparison of power consumption of mobile WiMAX, HSPA and LTE access networks," in *Proceedings of the 9th Conference of Telecommunication, Media and Internet (CTTE '10)*, pp. 1–7, June 2010.