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Reliable Energy-Efficient Multilayer Mechanism with Realistic Battery Model and QoE Support in Wireless MANETs

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Abstract— **Evolution in the telecommunications networks and the rapid advances made in wireless mobile communication networks, have taken computer networks to a new communication level. They now provide support for new mobile multimedia applications and are thus fostering the development of new network types and configurations. MANET is an important configuration of network for operations that employ mechanisms to enable dynamic self-configuration, self-optimization and self-healing, which is a challenging task for the routing protocols, new multimedia application and the battery energy consumption of wireless and mobile devices. These protocols are challenging because battery problems are more serious in this type of network and the existing protocols are not adapted to current problems, particularly mobile multimedia streaming, that can be found in most Internet flow. This paper proposes a reliable energy-efficient multilayer mechanism to address this to make improvements in the main current protocols. The proposal adds decision metrics to an energy-efficient computational intelligence technique based on Fuzzy-System with QoE, mobility and battery guarantees, choosing the best path in an efficient and accuracy way. The proposal has been evaluated in a network simulator.**

Index Terms— telecommunications, mobile multimedia, MANET, routing protocols, energy-efficient, QoE.

I. INTRODUCTION AND STATE OF ART

In recent years, there have been big advances in electrical, electronic and hence telecommunications equipment. The telecommunication systems have evolved into wireless systems and later mobile systems and new applications have emerged with added performance requirements. However, this rapid growth has led to an increase in battery energy consumption, especially in mobile devices, where there is no permanent infrastructure for energy supply. In addition, there are new data applications and videos that require a higher battery consumption to run and involve new applications and new telecommunications mechanisms to find energy-efficient solutions.

In addition, communications networks mechanisms are being challenged to increase the sensitivity of the transmission rates (transmission performance) for new multimedia applications and meet their

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performance needs. It is expected that the future networks architecture will have greater coverage, faster transmission speeds and more reliable guarantees so that the applications can include the concept of NGWN (Next Generation Wireless Networks) and FI (Future Internet), which should allow mobile telephone users to be connected anytime and anywhere [1].

One of the leading computer networks that can provide an efficient solution for these types of scenarios (which are already being widely used) is known as MANET (Mobile Ad hoc Network), a type of mobile network which has wireless devices for computers with dynamic self-configuration, self-optimization and self-healing as well as being without a fixed infrastructure. All these devices (mobile clients on laptops, smartphones, tablets, etc.) can act as routers and/or end users, and provide alternative routes in a wide range of scenarios. This type of network can be used in many scenarios such as FANETs (Flying Ad hoc Networks), VANETs (Vehicular Ad hoc Networks) and WSN (Wireless Sensor Networks), which can be either mobile or static [2], [3]. Fig. 1 exemplifies this.

Fig. 1. Wireless mobile Ad hoc network

This type of network sharing problem encountered in mobile telecommunication networks is caused by the limited battery energy capacity. As well as this shared problem, this mode of operation has no servers or control stations and control devices to monitor and balance the network traffic, such as BS (Base Station) or CHS (Cluster-Head Station) which are generally found in cellular networks, 3G and 4G network or WSNs. This poses a major new challenge for this type of communication networks, in addition to the battery power capacity: routing protocols.

This problem dates back to the origins of the rise of computer networks, where the routing protocols were (and still are) limited in their ability to determine the best route. They were almost always based on a decision about the best way to the shortest path, which might be the wrong decision. As noted in the literature, it is expected that new telecommunications networks will still be subject to these problems and that these will include battery power consumption. In view of this routing protocols will have to be adapted to these choices and efficient and effective strategies adopted for the multimedia flow of NGWN.

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The future routing protocols must be sensitive to factor mobility which is increasingly present in telecommunications networks, as well as to the user experience and the quality of the multimedia flow and battery management capabilities of mobile devices. At the same time, it must reduce battery energy consumption in accordance with the principles of green computing and maximize the network lifetime and hence connectivity [4], [5].

On the basis of these concepts and the assumptions of NGWN, this paper proposes a "Reliable Energy-Efficient Multilayer Mechanism" to solve the problems encountered in today's leading routing protocols that can be found and are classified in [6]. This mechanism integrates information about the upper and lower layers of the OSI model of computer networks with an intelligent system built in the Internet layer. It involves making use of the appropriate values of mobility, battery and user experience as the key metrics that estimate a multimedia transmission for current telecommunications networks.

The following section two will includes a brief discussion of the main papers related to this paper. Section three describes the proposal and the means involved to implement these mechanisms. In section four there is an analysis of the results obtained through the simulator and section five provides a summary of the final considerations.

II. RELATED WORKS

As stated in a previous section, it can be said that there are two major challenges facing next generation wireless cellular networks, especially the Ad hoc type: 1- how to address routing problems and their outdated protocols and 2- the energy depletion of mobile devices caused by the limited energy capacity of the batteries and the lack of a physical infrastructure system to recharge their energy [4]-[5], [7]. Fig. 2 summarizes this.

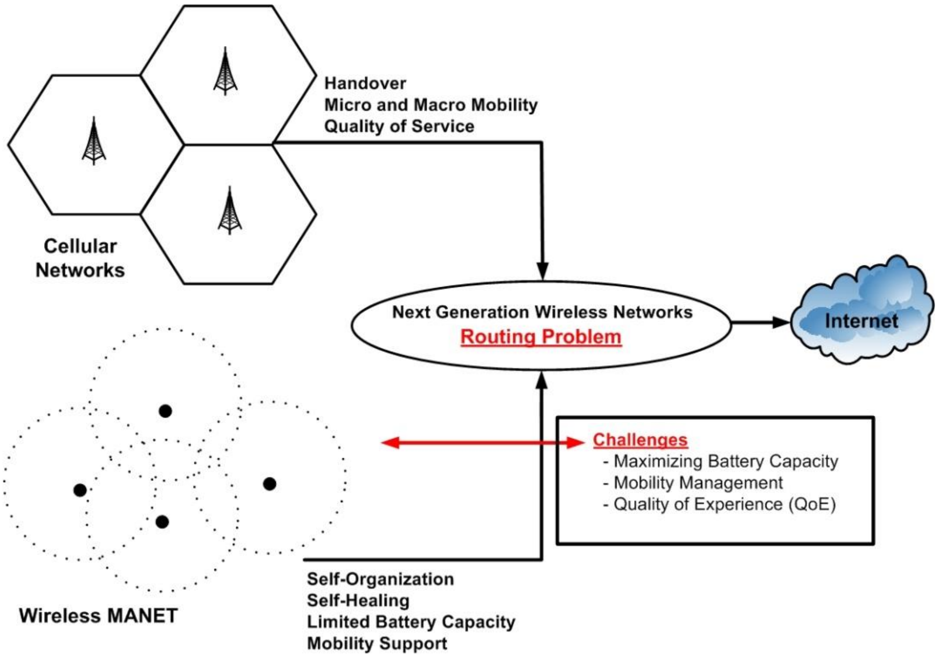

Fig. 2. Cellular and Ad hoc networks and the main challenges in the NGWN

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The energy depletion of a mobile device in an ad hoc network can disrupt communication in the telecommunications networks and lead to a premature death. This is because of a lack of wireless transmission to direct the flow of data to a destination. The lack of communication is the factor that precedes the problem of energy depletion in a network. This suggests that energy is an essential and decisive factor for maximizing the lifetime of a network.

In recent years, there has been a wide discussion about what should be done about the routing protocols. Many new protocols have been proposed and examined, especially with regard to energy. Some authors have set out new protocols and techniques that rely on transmission power as a decision metric while others are concerned with factors such as the energy capacity of the mobile device or predicting the expected useful life, etc. There is an in-depth discussion about this matter in paper [8]. The numerous studies in the literature can be separated into two groups: those that propose new protocols and others that provide new architectures, mechanisms or solutions to assist the current protocols.

A. New Protocols

Many of the current studies [9]-[12] seek to create new protocols in the search for energy efficiency of ad hoc networks and attempt to obtain satisfactory results in their experiments. In [9], for example, the authors consider two key metrics that are involved in the decision-making: the hop count (which is similar to many of the major protocols that are currently employed) and the “node degree” which measures the strength of the mobile device for a possible route. The authors evaluate the new protocol and compare with AODV, which is a reference-point between the protocols based on distance vectors algorithms.

The major focus of the authors of [9] is on VANETs, which are networks where mobile devices usually have a wide range of high speeds. By discovering and determining the routes of the next devices, the authors create a protocol that can achieve satisfactory results with regard to the final delay and the average rate of delivery, which are two important results in high mobility scenarios. The authors of [10] also propose a new protocol that is an extension of AODV, the AODV-L and include new information about decision making and direction, position, speed and the digital mapping of highways.

The authors of [11] create a new routing protocol for a dual technology, WLAN-WiMAX to route the packet transmissions in heterogeneous vehicle networks. The new protocol is adapted to topology changes that may be present in heterogeneous VANETs and are similar features to those found in mobile ad hoc networks, where the constant mobility and energy depletion of mobile devices may create or delete possible routes for the network flow. The new protocol improves the delay and packet delivery rate.

In [12], the authors propose a trust-based protocol for energy efficient routing for MANETs. They introduce an energy consumption model where the concept of energy factor (energy input) is the

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residual rate of energy for the initial energy of a node (mobile device). By means of this data, the authors create an energy-efficient system that takes into account the reliability of this factor in decision making, as well as among the participants of the network devices. The results show that both the delay and the overall overhead are reduced by increasing packet delivery and reducing energy consumption.

In [13], the authors balance the energy consumption and the end-to-end delay by putting forward a protocol based on the SPR (Stable Path Routing) Protocol. This involves employing parameters and meeting QoS requirements such as end-to-end delay, bandwidth, energy levels and other factors, and above all considering the delay and energy needed for making decisions about the best path, and obtaining satisfactory results (which are tested through the network simulator).

B. Energy-efficient solutions

Unlike many of the new protocols created by the authors cited above (and many others in the literature not mentioned here), the studies [14]-[17] take the trouble to optimize or improve the protocols currently in use. In some cases they have created improved systems for routing in the telecommunication systems and computers of current networks.

The authors of [14] improved the performance of their network and its flow, by reducing the routing load and jitter between nodes. To make this possible, they restricted the use of proactive routing protocols (since these constantly seek to update their routing tables and this results in a longer delay and hence a higher battery consumption). The authors also overcome these problems by using the DSR and AODV as strategies that ensure that the path can be predetermined from a source node to the destination and thus minimize instability.

The authors compared the DSR (Dynamic Source Routing) protocols with AODV in a setting where there are a lot of mobile devices and a signal-to-ambient-noise ratio and concluded that the AODV routing protocol consumes much less energy than the DSR, and has reduced instability. Even when the number of mobile devices increases gradually or there is an increase in the mobility of the devices, the authors also claim that there is effectiveness and efficiency in the network performance from the standpoint of the AODV protocol. According to the authors of [14], the protocol has a better flow, as well as less delay and power consumption.

In paper [15], the authors carry out an interesting discussion on different energy-efficient routing protocols. They cite the EPAR, EPLAR, QEPAR, LRPH and EMRGA protocols and provide some details about their features and capabilities. In addition, they carry out a comparative analysis on the basis of battery power efficiency, which involves comparing a range of protocols with regard to delay, overhead and battery consumption. This is aimed at improving operational quality from the standpoint of the network and QoS metrics.

In [16]-[17], the authors suggest a number of improvements to existing routing protocols. In [16], the authors make use of QoS values such as delay, throughput, bandwidth, etc. as an alternative means

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of saving energy. In [17], the authors employ two energy-aware routing algorithms for wireless ad hoc networks called RMECR and RMER (reliable minimum energy cost and reliable minimum energy routing). The algorithms [17] significantly improve the energy consumption, reliability and lifetime of wireless networks.

There are a number of other studies, not cited in this article, that also create new protocols and sometimes suggest new systems to improve routing. A brief analysis of these works, it is clear that the use of the metrics used by the authors mentioned above can be effective as a way of enabling us to save energy; however, we believe that the solution of this routing problem can lead to other different problems. In many of the works in the literature, created protocols and mechanisms can improve the energy efficiency of networks, but fail to solve the routing problems since they are unable to choose the best route for the whole system.

Thus, we believe that the creation of new protocols or mechanisms is not the most effective and efficient means of tackling this problem, since the new protocols are only devoted to addressing a particular issue, without providing a more complete solution. Thus, in our view, the existing routing protocols should be improved by incorporating the operation of a new system of measurements that goes beyond the two key metrics being used: number of hops and the transmission sequence number.

III. Energy-Efficient Multilayer Mechanism

In telecommunications and computer networks, MANET is a type of network that does not have a central device or special terminal designated as an access point where all communications converge and all the data must pass before being sent to their appropriate destinations. It is a kind of modern network that can be dynamically adapted to any wireless environment by managing mobility and providing quality for final systems.

As already discussed, this type of network involves two major challenges for NGWN: obsolete routing protocols and the battery capabilities of the mobile devices that are due to the lack of an infrastructure. Moreover, since it is a mobile network, the decision-making system must be sensitive to the aspects of mobility involved when choosing the best path. Large variations in the speed and sometimes the direction of mobile devices can affect either the creation or absence of new methods for their use [2], [4].

On the basis of what was discussed in the previous sections and the findings in the literature about the unreliability of traditional routing protocols, when new protocols have been created for a single problem and it has been solved, it has only led to many other problems. Thus, this paper proposes a reliable energy-efficient multilayer mechanism to improve the routing protocols. This takes into account a) the battery capacity of the battery of a mobile device, b) mobility, which is increasingly present in today's telecommunications and c) the quality of experience in multimedia streaming.

The mechanism is based on a fuzzy system that uses three input metrics that are the most commonly used replacements (number of hops and the sequence number of the mobile) for these

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paths. The metrics were selected on the basis of a study of the above related works and other findings, along with plausible reasons for their choices.

The first metric is provides mobility solutions and is of great importance to current networks because of the needs of NGWN and FI in the question of mobility. According to studies in the literature, over 50% of current Internet users are mobile (notebooks, tablets, smartphones, etc.). Because of this and the mobility requirements of MANETs handling mobility devices is a key metric for routing network traffic more effectively [2]-[5].

The second metric chosen is for the energy capacity of the battery and the amount of remaining energy in a mobile device. This is the reason why this is one of the main problems and challenges of MANET networks which lack a fixed infrastructure to recharge mobile devices or alternative energy standards in the protocols conventionally used.

The third and final metric chosen for the equation is the "QoE rate", which will be used to measure the final quality of a multimedia stream in a MANET network. The quantification and qualification of the QoE is very important for the fuzzy system of decision-making. This especially applies to today's telecommunications/cellular networks where companies and providers of mobile network services have increasingly applications turns to the multimedia stream and according with the literature, the percentage of this type of traffic is already over 40% of the entire flow of the Internet [2], [7].

A. Realistic Battery Support

In recent years, many researchers have sought energy-efficient solutions for telecommunications networks and computers and some energy models have been examined for wireless networks and ad hoc systems [4], [8], [15], [17]-[18]. However, before their experiments can be tested and proved, the authors must validate their achievements through practice tests, measurements based on mathematical models and simulations; With regard to the last of these, many of today's network simulators have no realistic battery models, which take into account the different types of transmission and this prevents the tests from having satisfactory outcomes.

The paper [19] provides mathematical models to characterize the battery behavior. The first work involves protocol parameters that are employed for analyzing the pattern of traffic, and the characteristics of the network topology. The second work examines the battery behavior and different rates of transmission and reception and their respective levels of battery consumption, in addition to the idle state of a device on the network.

The battery model proposed by [19], used by [20] includes the different battery states such as recovery rate and the four different types of networks for the transmission of telecommunications for fixed or mobile data: a) Sleeping state, when the device is turned off (negligible battery consumption); b) Transmission state, when the device is transmitting data (high battery consumption); c) Receiving state, when the device is receiving data (moderate battery consumption); d) Idle state, when the device is switched on but not being used (recovery battery – due to electrochemical process, the device can

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recover its battery energy) [5], [19]-[21]. Fig. 3 summarizes this.

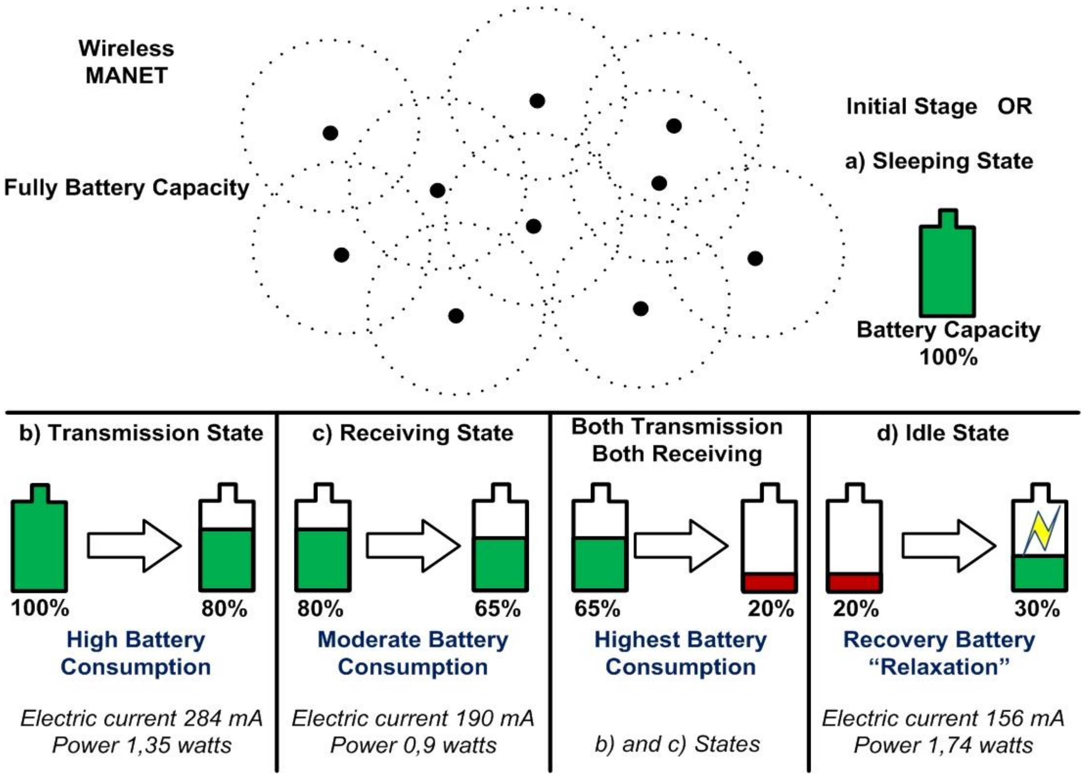

Fig. 3. Example of nonlinear energy model used by energy-efficient mechanism in MANET scenarios

An ion lithium battery that is found in most current electrical-electronic devices has two key electrochemical effects on the realistic battery model of the [5], [19]-[20]: a) Capacity rate or battery capacity and b) Battery Recovery , involving relaxation processes in batteries, where the battery recovers some energy in idle periods. The realistic battery model proposed by [19] seeks to estimate the lifetime of a lithium-ion battery on the basis of Equation (1); where: a) the α (alpha) is the battery capacity; b) β (beta) is the nonlinear behavior of the battery; c) n is the number of times that the equation is performed with a different k; d) I_{k-1} is the discharge current during the period k–1; e) Function A is the impact of nonlinear behavior in battery discharge; f) L is the battery life time; g) t_k is the time duration for period k and h) t_{k-1} is the time duration for period k-1.

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

B. Quality of Experience

Unlike QoS (which is concerned with measurements from the standpoint of the network), the term QoE includes an understanding of the multimedia and can be regarded as a type of metrics for assessing quality via user perception to the human visual system [22].

Although QoE is related to QoS, it differs to the extent that it expresses user satisfaction (QoS and QoE are different but can be linked), both objectively and subjectively, by evaluating the visual information from the human brain and extracting features such as color, brightness, contrast and lightness. It also seeks to evaluate QoS metrics and flow and delay and continues by assessing the

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human sensitivity that is essential for multimedia streams. In addition, it provides a fundamental support for architectures and network protocols, by improving the quality of applications in NGWNs. In general, there are two basic ways to evaluate the quality of a video: subjective evaluation methods and objective evaluation.

Subjective evaluation measures the quality of multimedia applications and draws on the opinions of the user on the basis of his experience and this is confirmed by scores (grade quality) made by the viewer. The most widely known subjective metric is the MOS (Mean Option Score) the scale of which is obtained through testing and by employing a methodology to a set of people. This measures the quality level of a video sequence by mapping a scale of 1 to 5 on Table I.

TABLE I. MEAN OPTION SCORE

MOS	QUALITY	PROBLEMS
5	Excelent	Imperceptible
4	Good	Perceptible
3	Regular	Light nuisance
2	Bad	Heavy nuisance
1	Poor	Low visibility

The objective evaluation methods are calculated by means of algorithms and mathematical equations that are used to analyze multimedia parameters and on the basis of this analysis, estimate the quality of a video stream. These estimates are similar to the results obtained by evaluating subjective tests and based on comparisons that are made when mapping the values of objective metrics. The main objective metrics related to the QoE are PSNR (Peak Signal to Noise Ratio), SSIM (Structural Similarity Index) and VQM (Video Quality Metric); the first of these, which is the most common and simplest is found in almost every article and publication in the current literature.

The PSNR is based on the use of MSE (Mean Squared Error) so that there is a frame-by-frame analysis (frame-to-frame) of the video received by the user with the original video sent. This is calculated in dB (decibel) and obtained from the original frame and the frame received (as shown in equation 2 and equation 3 below) [22]-[23].

$$MSE = \frac{1}{M.N} \sum_{m=1}^{M} \sum_{n=1}^{N} |o(m,n) - d(m,n)|^2 \qquad (2)$$

Where each square has M x N pixels and o (m, n) and d (m, n) are lighting pixels at positions (m, n) of the frame. Thus, the PSNR is the logarithmic ratio between the maximum value of the brightness signal and the ambient noise (MSE). The PSNR is calculated by Equation 2.

$$PSNR = 10 \log \frac{255^2}{MSE} \qquad (3)$$

C. Fuzzy System Decision

Unlike traditional logic that works with exact values, fuzzy system logic allows a degree of uncertainty, which makes it ideal for fuzzy variables such as mobility speed, QoE rate and battery

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capacity adopted in this work. A fuzzy set has an associated membership function which defines a degree of membership for each element of the set series which can vary within the real interval [0,1]. The obtained value of the membership function for a given element shows how that element belongs to the set. Thus, an element can belong to one fuzzy set rather than others [24].

A fuzzy inference system has three main blocks of components: a) Fuzzifier; b) Inference engine linked with fuzzy rules; and c) Defuzzifier. The fuzzifier uses the fuzzy sets defined for input variables and their membership functions as well as defining the degree of relevance of a real variable about each of the fuzzy sets (Fuzzification method). After that, the inference engine uses the data resulting from the fuzzifier to determine the use intensity of the inference fuzzy rules and obtains the fuzzy set resulting from the output. Finally, the defuzzifier employs some method of defuzzification to convert the output fuzzy set to an actual value that can be processed outside the system.

The fuzzy system will identify the paths with low mobility (to maintain topology for a longer time) with high battery energy content (so that it can remain active for a longer period) and a good QoE rate (for paths/routes that are no longer being used in other broadcasts).

Mobility is classified as follows: a) Low (0 to 6 m/s); b) Medium (from 5 to 12 m/s); and c) High (from 10 m/s). The battery capacity is divided as follows: a) Low (0 to 20%); b) Medium (20% to 70%); and c) High (from 60%). And QoE rate is classified as follows: a) Low (0 to 25 dB); b) Medium (22 to 31dB); and c) High (from 30 dB).

The combination of these three inputs generates an output that can be: a) Poor path; b) Good path; and c) Excellent Path. When the result of the membership function is equal to or greater than 0.65, it means that a new path will have low mobility (less change in the network topology) with a good power supply (a route with longer life) and a good QoE rate (multimedia stream have better quality). Fig. 4 shows the fuzzy system used with fuzzy input (trapezoidal) and fuzzy output in 3D format.

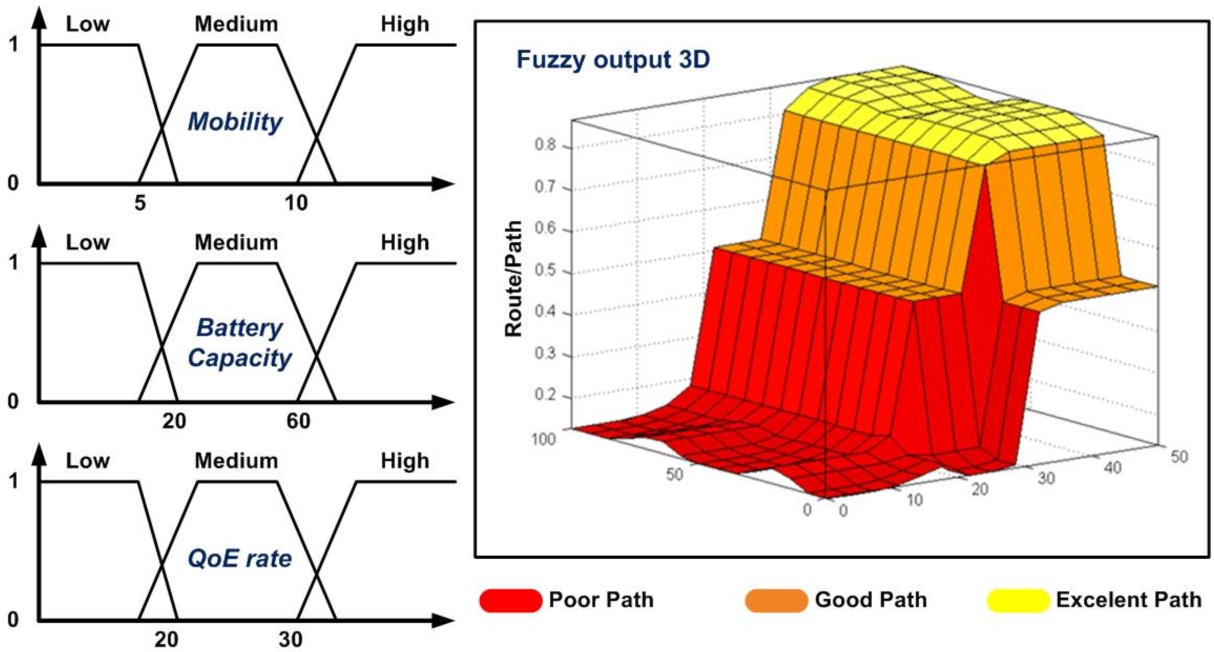

Fig. 4. The fuzzy system input and the fuzzy output in 3D

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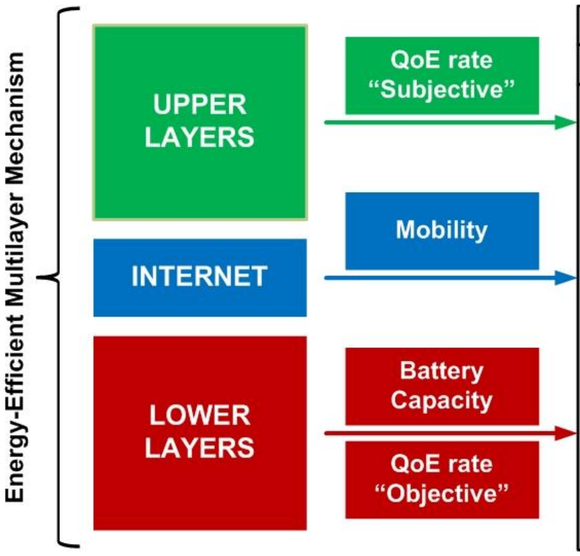
The fuzzy output 3D graph shows the decision-making required for the energy-efficient multilayer mechanism, where: a) red areas correspond to poor routes and the table routing is not updated; b) orange areas correspond to good routes and the table routing is updated, but with low priority; c) yellow areas correspond to excellent routes and table routing is updated with high priority.

The fuzzy system has a greater importance (degree of pertinence) in the "QoE rate" and remaining battery capacity. The mobility metric has a low degree of pertinence. These are factors that are crucial to decision-making, especially as a way of saving energy in the area of green computing and to provide final end quality to the multimedia stream for the next generation of MANETs. Fig. 5 shows the energy-efficient multilayer mechanism and some of the fuzzy rules.



Main fuzzy rules (Inference Enfine)			
Mobility	**Battery**	**QoE**	**Output Result**
Low	Medium	Medium	Good Path
Low	Medium	High	Good Path
Low	High	Medium	Good Path
⋮	⋮	⋮	⋮
Low	High	High	Excelent Path
Medium	Medium	High	Excelent Path
Medium	High	High	Excelent Path
⋮	⋮	⋮	⋮
Medium	High	Medium	Good Path
Medium	Medium	Medium	Good Path
Medium	Medium	High	Good Path

Fig. 5. Multilayer mechanism and main fuzzy rules used

IV. Simulation Results and Performance Evaluation

This section shows the performance appraisal of the mechanism proposed; the performance evaluations were carried out through Network Simulator (ns-2) and Evalvid Tool [25] (for video transmission). The simulations were carried out in scenarios with a random mobility (with different speeds and directions). The ad hoc nodes were configured as routers and clients at the same time. That section was divided in three subsections explaining respectively the network, battery consumption and quality of experience results.

Four routing protocols were used for the simulations: OLSR (Optimized Link State Routing), AODV (Ad Hoc On-Demand Distance Vector), DSDV (Destination-Sequenced Distance Vector) and HYBRID (a representative example, both proactive both reactive protocol). These protocols are standard in many studies and the most widely used protocols. The HYBRID protocol was used as a representative example [26].

The battery energy consumption of the mobile devices is explained in Section 3. A.; There are different levels of battery consumption depending on the type of transmission and these can be categorized as: a) Sleeping state; b) Transmission state; c) Receiving state and d) Idle state. This paper

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uses 4.74 V to set up the battery consumption of the network devices. The mobile network devices have an initial energy of 40 joules [5], [22]-[24], [31].

The scenario for evaluating the architecture comprises mobile users with random mobility (using Random Waypoint Mobility Model – ns-2 configuration). Since the mobility devices are moving dynamically at a different speed, the routes between the source and destination change during the transmission. It is necessary to recalculate the best route from the source to the destination device.

A. Network Results

Fig. 6 below shows that the throughput of the energy-efficient multilayer mechanism is higher than in the other protocols used. The improved protocol searches for mobile clients/devices with low mobility, a good QoE rate and a higher remaining battery life. It is a way of saving energy and keeps the best route active for a long time while providing a continuous data flow. The multilayer mechanism and the other protocols stabilize the flow of data over time, although the energy-efficient mechanism yields better results for throughput, because it takes into account the results of mobility and battery testing and choosing best routes and best mobile devices. The energy-efficient multilayer mechanism had an average throughput of 0.17 Mbps, AODV had 0.15 Mbps, HYBRID had 0.11 Mbps and OLSR had 0.09 Mbps.

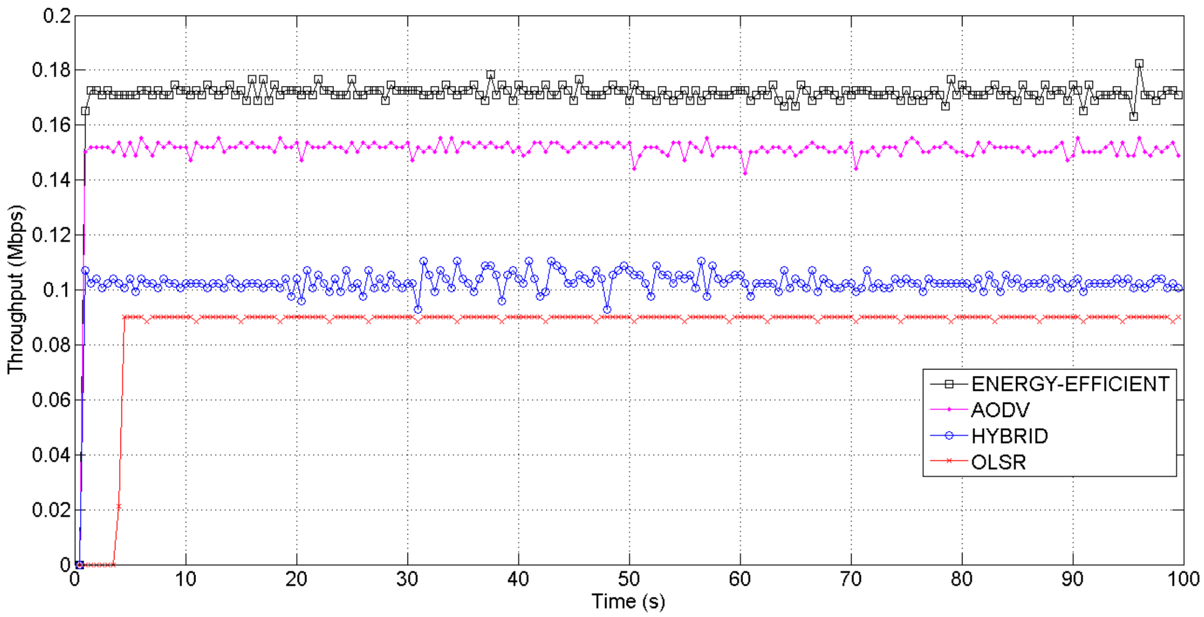

Fig. 6. Throughput of the energy-efficient mechanism and other protocols

We have included a new protocol for the next simulation results, with a pseudo-behavior-based system similar to the AODV protocol, because it is based on distance vector algorithms. In the previous simulation results, AODV achieved better throughput results with the exception of energy-efficient mechanism. In light of this, we decided to include the DSDV protocol in the next test.

Fig. 7 shows that the multilayer mechanism proposed again shows efficiency by being able to maintain a data flow that is better than the other protocols. In the new scenario, where there is high

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mobility variation, DSDV obtains results that are close to those of AODV. The average throughput of the energy-efficient mechanism achieves a rate of about 0.33 Mbps, AODV about 0.27 Mbps and DSDV about 0.23 Mbps. The other two protocols HYBRID and OLSR had poor throughput results with 0.02 and 0.01 Mbps respectively.

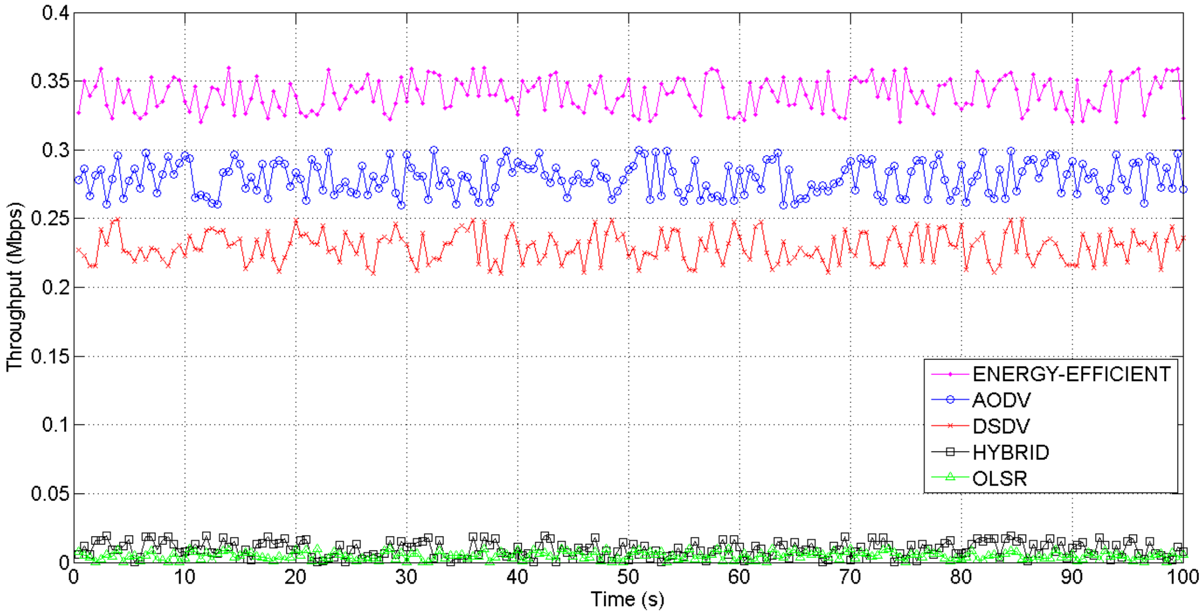

Fig. 7. Throughput of the energy-efficient mechanism and other protocols (with DSDV)

Fig. 8 shows the results of delay in a random scenario; this involves making a comparison between the energy-efficient mechanism and other protocols. Delay is an important result, because it can degrade the data transmission and hence disturb the communication network. The energy-efficient mechanism and the other protocols (except for OLSR) had no delay or negligible delay (up to 0.02 milliseconds) when forming the table routing. When setting up a new routing table, the OLSR had a period of delay of about 0.37 milliseconds.

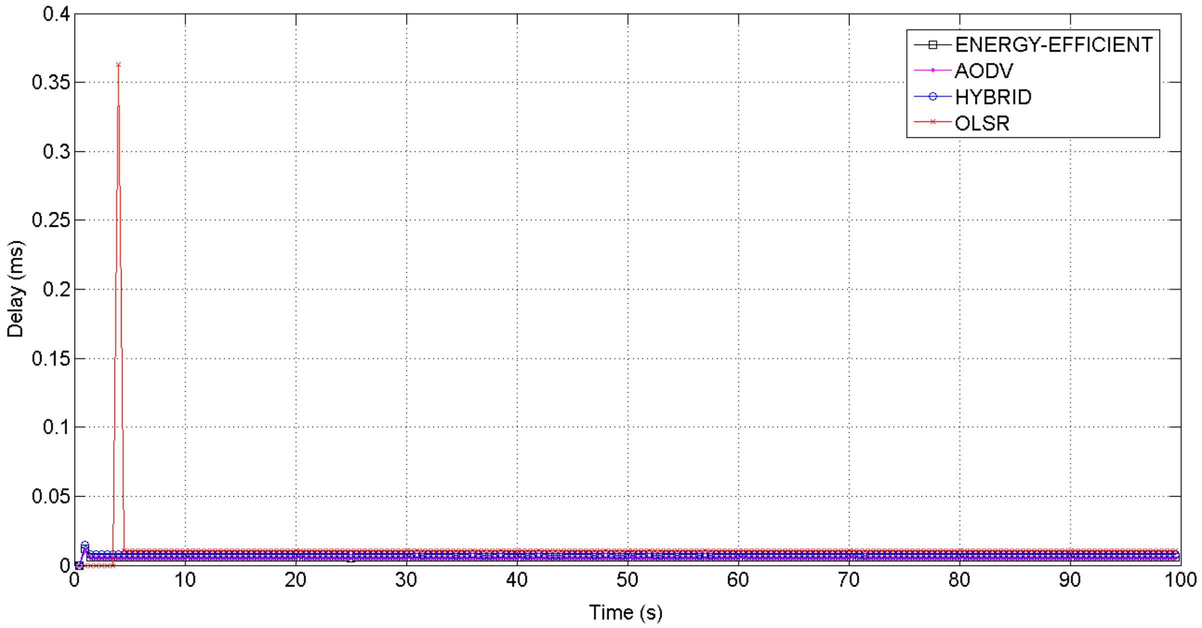

Fig. 8. Delay of the energy-efficient mechanism and other protocols

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B. Battery consumption results

This subsection describes the battery power consumption of the entire network using the protocols described in this paper. Fig. 9 shows the battery consumption of the energy-efficient mechanism and compares it with the AODV, OLSR and HYBRID protocols. The battery consumption of all the protocols used is greater than the battery consumption of the energy-efficient mechanism, which had a final discharge battery of 9.9 Joules. The AODV, HYBRID and OLSR protocols had a final discharge battery of 35.8, 36.4 and 37.3 Joules respectively.

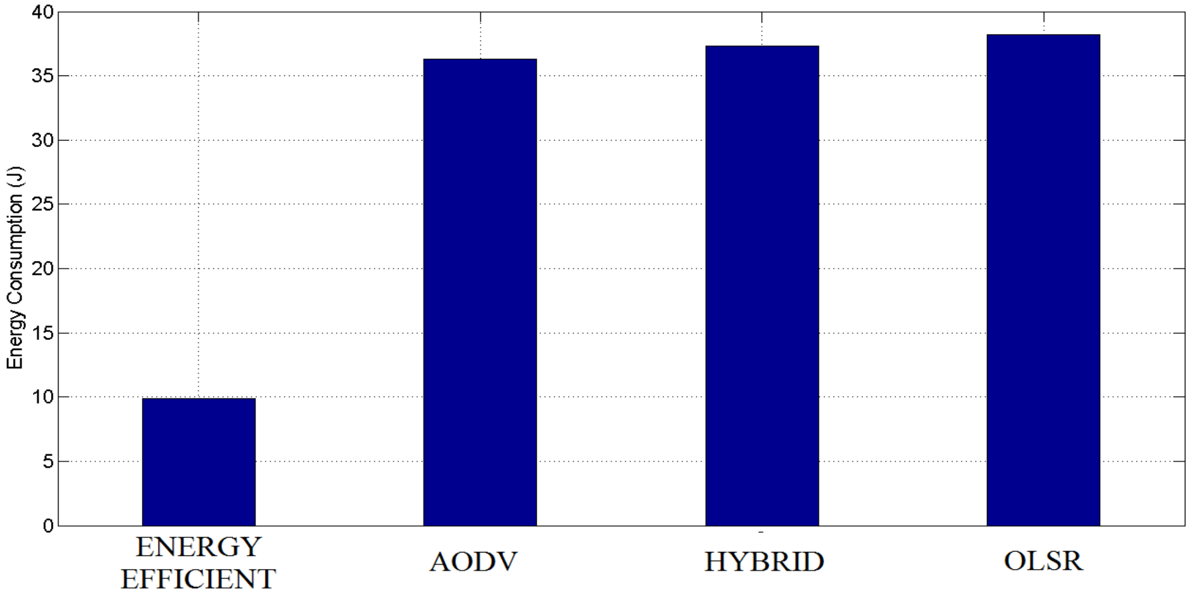

Fig. 9. Battery energy consumption

Fig. 10 shows the battery consumption of three specific mobile devices which were chosen because they are representative examples of different kinds of battery behavior. They have different battery states, as shown earlier in Fig. 3.

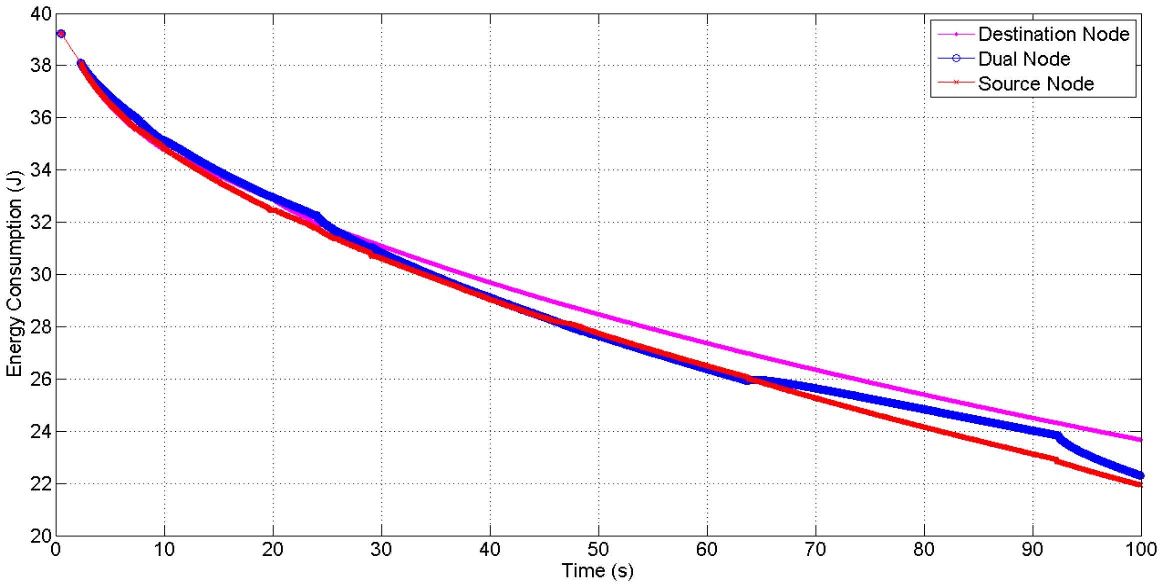

Fig. 10. Battery consumption of three different mobile devices

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As can be seen, Fig. 10 above illustrates the battery discharge rates of three different mobile devices for the consumption of three different batteries. One of the mobile devices is the "Destination Node" that only receives (Receiving state) data during the entire network simulation time. As expected, this mobile device had lower battery consumption than shown in the diagram.

Other of the mobile devices is the "Source Node", which only transmits (Transmission state) a data stream during the network simulation time. As expected, this mobile device had more battery consumption than the others, because it is only transmitting data.

The last device is "Dual Node". This mobile device had transmission and receiving state and the highest battery consumption of the network, because it was transmitting and receiving data at the same time and for longer periods, which reduced the lifetime of its battery. It should be noted that the line had major changes. The nonlinear behavior can be explained by the fact that at certain moments, this mobile device enters an Idle state and can recover some parts of its battery capacity. In this way, it is able to maximize its useful lifetime, and hence that of the entire network.

C. Quality of experience results

Apart from the results of the network and battery consumption, the benefits of the energy-efficient mechanism can also be measured through objective (quantitative) and subjective (qualitative) assessments of quality of experience.

The simulation shows that the two video streams with low resolution executed with an energy-efficient mechanism were superior to the same videos executed with the other protocols (AODV and OLSR), as can be seen in Fig. 11, Fig. 12 and Fig. 13 below. This superiority can be assessed from a subjective standpoint (i.e. through the human visual system), that determines the quality of the video stream by providing a visualization of the frames and conducting a subjective analysis with the aid of the YUV player and MSU video quality measurements [27]-[28].

In Fig. 11, both videos can be a serious nuisance and have low visibility and clearly the quality of these videos for the end user is poor. In Fig. 12, both videos are of a good quality, with only minor flaws and overlapping images. Fig. 13 has excellent quality and no errors.

Fig. 11. Two subjective videos quality over OLSR protocol – low visibility

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Fig. 12. Two subjective videos quality over AODV protocol – good quality

Fig. 13. Two subjective videos quality over energy-efficient mechanism – excellent quality

Table II shows the level of video quality. The results show that the video quality with the Reliable Energy-Efficient Multilayer Mechanism transmission is excellent and better than that of the other protocols tested, which corroborates the subjective results obtained in the previous Figs. The following table shows the results of PSNR, SSIM and VQM metrics, from an objective standpoint .

TABLE II. QOE METRICS OVER ENERGY-EFFICIENT MECHANISM AND OTHER PROTOCOLS

QoE Metric	OLSR Protocol	AODV Protocol	Energy-efficient Mechanism
PSNR	19.2	40.4	45.3
SSIM	0.8	0.9	0.9
VQM	3.2	0.7	0.4

After obtaining the results from the two videos before, we conducted another round of experiments with a high resolution-definition video, using the same scenarios tested by the videos earlier. As can be seen, the results remained the same.

The energy-efficient mechanism has an excellent quality from a subjective standpoint, with a frame/image that has an excellent visualization, with no distortions, flaws or delays. However, the same results were not obtained from the AODV protocol, which in the previous tests had a good quality but low quality video. On this occasion, the high resolution video with an AODV protocol had some minor flaws and delayed the other image overlays. The OLSR which had obtained a poor result

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in the previous result was not tested. Fig. 14 and Fig. 15 show these subjective results.

Fig. 14. Subjective video quality over AODV Protocol (High definition – 720p)

Fig. 15. Subjective video quality over Energy-Efficient Cross-Layer Mechanism (High definition – 720p)

Table III shows the level of video quality from an objective standpoint by means of the objective QoE metrics: PSNR, SSIM and VQM. The results show that the video quality with the Energy-Efficient Mechanism was again higher than the other protocols tested, which supports the subjective results obtained in the previous Figs.

TABLE III. QOE METRICS OVER ENERGY-EFFICIENT MECHANISM AND OTHER PROTOCOLS

QoE Metric	AODV Protocol	Energy-efficient Mechanism
PSNR	13	21.1
SSIM	0.8	0.9
VQM	2.8	0.8

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V. Final Considerations

The results in this paper show that a better performance was achieved than with traditional routing protocols such as AODV, OLSR and HYBRID option that were employed in the literature and examined in this paper, owing to the use of the "Reliable Energy-Efficient Multilayer Mechanism". The proposal included relevant metrics for measuring techniques of computational intelligence and achieved satisfactory results in the MANETs. It provides greater durability for the telecommunication network operation and greater connectivity for mobile clients and their mobile applications with a better end quality in the mobile multimedia stream.

Owing to the reliable energy-efficient mechanism, mobile customers were able to a) choose the best paths, b) maximize the network lifetime and the battery energy capacity of the mobile devices, c) maximize the throughput and reduce interruptions and as a result of this, d) obtain a better network performance, from the standpoint of the network and e) improve the quality of service and experience (QoS and QoE results) of the end users, as well as the performance, from the standpoint of the users.

The routing mechanism improves the way mobile networks operate through the use of the new measurements and by employing a fuzzy system decision mechanism (computational intelligence technique); this saves battery capacity and provides a better quality for the network, especially with regard to the multimedia flows. The use of a realistic battery model is another important point, because this shows the real situation of what occurred with the battery energy consumption according with the different batteries states. The recovery rates of the lithium battery are observed when the nodes are in an idle state and this really demonstrates what happens to mobile devices when there are not any active routes.

As a result of the tests conducted in this paper, we came to the conclusion that the "Reliable Energy-Efficient Multilayer Mechanism" achieved a gain of almost 75% (in the linear energy model) and up 23% (in the realistic battery model). Furthermore, there are considerable gains in the network throughput in the tests that are run in the network simulator. The proposal provides an accurate and efficient battery model that can be combined with an intelligent routing mechanism for the network traffic in a way that addresses questions of energy, mobility and QoS/QoE guarantees.

In future studies, we intend improve the fuzzy system mechanism by adding new measurements such as signal strength and distance and extending the range and increasing the speed of the mobile devices for the transmission and receiving data. We intend to test this out with different kinds of technology, including micro and macro mobility and dual channel interface and operating on 3G, 4G and LTE systems, and thus maximize the possible number of routes.

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