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# IMPROVEMENT OF ENERGY EFFICIENCY ON A MOBILE AD-HOC NETWORK (MANET) USING ENERGY OPTIMIZATION ALGORITHM

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## Abstract

This paper presents the improvement ofenergy efficiency on a mobile ad-hoc network(MANET) using an energy optimization algorithm (EOA). The study addresses the issues of high energy consumption in MANET application. This was achieved by developing an EOA which considered the dynamic behaviour of nodes and adjusts the energy level, to minimize unnecessary energy consumption, especially during inactive periods. The algorithm was integrated in MANET nodes and simulated over 100 minutes of communication. The results in every 10 min of communication is 73.35%, with 4.06J of energy consumed per second. The results obtained were validated using ten-fold cross validation approach over 100minutes of nodes communication process and theyreported an average energy level of 73.96%, then 4.5J/s for the average energy consumed. Overall the result showed that the energy level of the nodes over 100minutes of communication remained 73.96%, which is very good, and will improve the application time of the nodes. More so, a comparative analysis of the EOA with a rule-based energy conservation algorithm in MANET, reported a reduction of 49% in energy level with EOA, and also 22.62% decreased in energy consumed per seconds with EOA.

**Keywords: Energy Optimization Algorithm; Mobile Ad-hoc Network; Energy Efficiency**

## 1. INTRODUCTION

The advancement of wireless communication technologies has facilitated the interaction between humans and their environment through electronic gadgets embedded with wireless ad hoc networks. Mobile ad-hoc network (MANET), as defined by Jatinkumar and Hossam (2021), is a decentralized type of wireless network composed of interconnected mobile devices that can configure themselves for connectivity and communication without the support of external physical network infrastructures such as base stations or antennas. This technology has dominated research in the field of wireless networks for over five decades (Gharaibehet al., 2017).

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MANET offers numerous advantages, including flexibility, low cost, simplicity, and rapid application in various fields such as emergency operations, medicine, military, offices, agriculture, entertainment, smart cities and disaster recovery among others (Buzzi et al., 2016; Quy et al., 2019; Quy et al., 2020; Muthumayil et al., 2021). However, MANET also faces challenges, as noted by Deep et al.(2022) and Sathish et al. (2022) such as poor Quality of Service (QoS) due to high energy consumption by nodes, limited bandwidth, heterogeneity, continuous route changes, limited wireless range, and packet loss. In particular, the energy consumption issue has been identified as the most difficult challenge to address in MANET, often resulting in node failure and affecting network dynamics and overall performance (Wang et al., 2018).

Numerous studies have been conducted to understand the reasons behind the power-challenging issues in MANET. Sumathi and Vimal (2022) highlighted that the ability of every node to route, send, and receive files significantly impacts the amount of energy consumed, leading to node failure. Manjula and Datta (2018) identified limited battery capacity as a primary cause of power challenges in the network. Additionally, Muthumayilet al. (2021) revealed that the data management process of traditional routing protocols, which often involves handling large amounts of data, prolongs the time of data delivery and increases power consumption in MANET.To address these issues, numerous literaturesworks on energy efficiency strategies have been conducted in recent studies on MANET. Many of these studies identified the problem as an optimization challenge and applied nature-inspired algorithms. For instance, Sumathi et al. (2022) argued that ant-based optimization (ABO) consumed more energy during the computing process, which impacted on network quality. In a similar vein, the author applied a probabilistic prediction approach to enhance ABO performance and achieved better energy efficiency compared to ABO.

More recently, Vinoth et al. (2023) proposed an energy-saving optimization-based routing protocol that considered node route energy threshold level, distance, and destination between packet nodes. The results, when tested and compared with ABO, showed a 12.2% improvement in energy efficiency. However, Sheng et al. (2022) argued that traditional optimization algorithms do not adequately address the issues of end-to-end delay and energy efficiency. Furthermore, based on evidence from further research, it was observed that conventional energy-aware routing protocols do not directly address the root cause of high energy consumption in the node, but rather focus on routing optimization to indirectly minimize energy consumption. Hence, there is a gap between minimizing high energy consumption in MANET and improving the overall quality of services. Hence this paper proposed an EOA algorithm which effectively manages the rate of energy consumption in MANET, while sustaining service quality.

## 2. DESIGN METHODOLOGY

The methodology adopted for the study begins with the energy consumption problem definition using a mathematical model, then energy-aware algorithm was developed using the sleeping scheduling technique. The network node thatformulates the MANET was optimized using the energy optimization algorithm to monitors the behaviour of the nodes and regulates the rate at which energy is consumed, so as to improve energy efficiency.

## 3. THE ENERGY CONSUMPTION PROBLEM FORMULATION IN MANET

The energy consumption problem of MANET was mathematically defined by Zongshan et al. (2020) considering the transmission operation of the nodes. This was achieved considering the energy when x-bit data was transmitted to obtain$E_y$ through d distance as shown in equation 1;

$$E_y(x,d) = \begin{Bmatrix} xE_{elec} & + x\varepsilon_{mp}d^2, & d < d_o \\ xE_{elec} & + x\varepsilon_{mp}d^4 & d \geq d_o \end{Bmatrix} \quad (1)$$

The energy consumption during the reception $E_{Ra}$of x-bit of data is given as;

$$E_{Ra}(x,d) = xE_{elec} \quad (2)$$

The energy consumption by the cluster head (node which collected multiple data from other nodes, i.e node with the highest energy) to fuse x-bit data is given as;

$$E_{Ra}(x,d) = xE_{elec} \quad (3)$$

Where $E_{elec}$ presents the consumed energyduring the transmission of 1bit of data; $E_{DA}$ is the consumed energy during fusion (multiple data integration) of 1-bit data; $d_o$ is the distance between the attenuated energy of signal amplifier and is defined as;

$$d_o = \sqrt{\frac{\varepsilon_{fe}}{\varepsilon_{mp}}} \quad (4)$$

where $\varepsilon_{mp}$ presents amplified energy power, $\varepsilon_{fe}$ is the energy required for the power amplification. Equation 1 formulated using Equations 2-4 presented a model of the energy consumed in MANET during transmission and reception of x-bit data. However, the equations only consider the energy consumption related to data transmission, reception, and fusion, and do not take into account other energy-consuming activities in MANETs, such as node mobility, overhearing, idle listening, and protocol overhead. According to Axidaet al., (2021), ignoring these factors may limit the accuracy and comprehensiveness of the model. To this end, there is a need for a model which considers the dynamic behaviour of nodes in MANET and then formulates the energy consumption problem model.

### 3.1 An Improved Model of the Energy Consumption Problem for MANET

What triggered the need for an improved model was to ensure that all the behaviour of nodes within the MANET is captured and used to determine the overall energy consumed during operation. Let's consider a MANET with N mobile nodes, indexed by $i = 1, 2 \ldots N$. Each node i has an initial energy level $Ei(0)$ and consumes energy during transmission, reception, idle, and sleep modes.

Let the energy level of the node i be represented as $Ei(t)$ at time t; let the power consumption rate of the node i during transmission at time t be presented as $P_{it}$; let power consumption for reception at time t for node i be $P_{ir}$; Now considering other behavior of the nodes like sleep and idle at time t, let the respective power consumed be $P_{is}$ and $P_{iId}$. Having characterized the behavior of the mobile nodes which can occur at time t, the equation of the energy consumption was formulated as;

$$Ei(t+1) = Ei(t) - [P_{it} * T_{ti}(t) + P_{ir} * T_{ir}(t) + P_{iId} * T_{Id}(t) + P_{is} * T_{is}(t)] \quad (5)$$

Where:

$T_{ti}(t)$ is the duration of time that node i spends in transmission mode at time t.

$T_{ir}(t)$ is the duration of time that node i spends in reception mode at time t.

$T_{Id}(t)$ is the duration of time that node i spends in idle mode at time t.

$T_{is}(t)$ is the duration of time that node i spends in sleep mode at time t.

The total energy consumption for the entire MANET at time t can be obtained by summing the energy consumption of all nodes:

$$E_{total}(t) = \Sigma \, Ei(t), \text{for} \quad i = 1 \text{ to } N \tag{6}$$

This energy model was used for analyzing the energy consumption in a MANET, considering different scenarios, network configurations, and energy management strategies. It was also used for evaluating the performance of routing protocols, scheduling algorithms, and other energy-aware mechanisms in MANETs.

## 4. OPTIMIZATION ALGORITHM FOR ENERGY CONSERVATION IN MANET (EOA)

The optimization algorithm for the management of energy conservation in the MANET is inspired by the sleep scheduling techniques based on the power management approach by Niranjan and Ashok (2016). In the study, the location of neighbour nodes and network topology was used to develop the sleep algorithm which minimized energy consumption in MANET, However, Dimitris and Varun (2020) posited that one potential limitation of using the location of neighbour nodes and network topology to develop a sleep algorithm for minimizing energy consumption in a Mobile Ad Hoc Network (MANET) is that some environmental scenarios within the network like smart adjustment of transmission power, energy estimation, load balancing, etc., which are equally vital actor to ensure node energy is conserved. In addition, Kanellopoulos (2017) posited that the approach has too much reliance on the location information of neighbouring nodes. This is because inaccurate location information may result in suboptimal sleep scheduling decisions, leading to higher energy consumption and reduced performance of the MANET. There is a need for an algorithm that considered many other factors during the nodes' operation process and make energy-efficient decision.

The new algorithm considers node operation characteristics such as routing decision, energy estimation, transmission power adjustment, sleep optimization and load balancing to develop a dynamic model that will improve the energy conservation rate during the active state of the nodes. For the energy estimation process, the idea was to nodes can monitor themselves and use energy information such as consumption rate, battery level, and energy consumption during the transmission or receiving of data. The algorithm was designed to enable nodes to communicate with neighbour nodes with enough energy and also used energy-aware routing mechanism to select optimal path for the transmission of data considering nodes with higher energy level. The power of transmission is dynamically adjusted based on the receiver locationto reduce energy consumed during the process and at the same time not affect quality of service. During the idle mode of the nodes, the algorithm ensures that the nodes are put to sleep and also during active modes, it monitors the traffic load and balances to maintain energy level which can rapidly degrade due to congested clusters on one node.

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For the energy level estimation process, let the E represent the energy of the nodes i, B represents the battery capacity of the node, R represent the consumption rate of energy and the energy consumption during transmission or reception of data is represented as C. The relationship between these variables was used to formulate the energy level estimation model as in equation 7.

$$Ei = Bi - RC(i) \quad (7)$$

Equation 7 was used by the node for the estimation of the remaining energy of the nodes during the ongoing communication process. The captured energy level estimation informed the approach the algorithm used on minimizing energy constraints, either through load shedding (see equation 11) or prevention of energy-intensive communication participation as described in equation 9. During the communication process, the node selection model in Equation 8 was utilized;

$$N_i = \{j \mid E_j \geq E_{threshold} \& \, dij \leq d_{max}\} \quad (8)$$

Where $N_i$ presents a cluster of neighbour nodes,$E_{threshold}$ is the energy threshold estimated using Equation 7, dij presents the distance between node i and j, $E_j$ is the receiver neighbor node energy. Equation 8 helps the nodes to select nodes that are closer and also has higher energy level so to prolong the network lifetime and reduce energy consumption. Similarly, the estimated energy level was to develop energy- aware routing model in equation 9 employed for the determination of the optimal path for packet transmission between node i and j. The energy-aware routing model was presented as;

$$P_{ij} = \text{argmin}\{w_{ij} \mid E_i \geq E_{threshold}\} \quad (9)$$

Where $P_{ij}$ presents the path for routing between node i and j, $E_i$ presents the level of energy for i node, and the weighted link between node i and j is represented as $w_{ij}$; $E_{threshold}$ is the energy threshold. Furthermore, during the data exchange, the energy required for the process by node i is adjusted according to the position of node j, based on receiver distance and pathloss exponents as stated in equation 10;

$$P_{tx} = (d_{ij})^\wedge\alpha \quad (10)$$

Where $P_{tx}$ is the power is required for the communication process between the transmitter i and receiver j, α presents the pathloss exponent and $d_{ij}$ is the distance between the transmitter i and receiver j. However, when the node is idle, the sleep mode optimization model was used to determine the sleep mode for the node considering the network traffic and energy level. The idea is to create a balance between energy saving and communication responsiveness. For the sleep optimizer, let the sleep model for node i be presented as Tsl, then $T_{load}$ present the expected traffic load, energy level represented as Ei be used to formulate the model as;

$$Tsl = \text{argmin}\{Tsl \mid T_{load} \leq Ei * Tsl\} \quad (11)$$

Equation 11 was used for the sleep optimization of the nodes and ensures prolonged sleep mode when inactive, while being sensitive to the incoming signals from other neighbouring nodes. The total load on node I is presented as $T_{load\,(i)}$, the average traffic load is presented as $T_{avl}$, energy level $E_i$ and $E_j$ are used to monitor $T_{load\ (i)}$ and balance accordingly based on energy level considering the neighboring nodes $N_i$ as shown in equation 12;

$$T_{load\ (i)} = T_{avl} * (E_i / \max\{E_j \mid j \text{ in } N_i\}) \quad (12)$$

Equation 12 ensures load balancing on the nodes using information such as energy level and average load total load of the nodes i and j nodes neighbors $N_i$ to balance traffic and assign more packets to nodes with maximum energy level.

**4.1 Energy Optimization Algorithm (EOA)**

1. Start
2. Initialize node parameters:
   i. Set the initial energy level of all nodes in the network, E(t=0), based on their battery capacity.
   ii. Set the energy consumption rate of all nodes, C, based on their hardware specifications.
3. Monitor ongoing communication activities:
   i. Track the communication time, T, and transmission power, P, for each communication activity in which a node is participating.
4. Estimate energy consumption due to communication activities:
   i. Calculate the energy consumption due to ongoing communication using Equation 6
5. Update energy levels:
   i. Update the estimated energy level of each node at time t+1 using the equation 7
6. Neighbour selection:
   i. Select neighbours for communication-based on their energy levels and distance, preferring energy-sufficient neighbours that are closer to conserving energy using equation 8.
7. Energy-aware routing:
   i. Determine the optimal path for data transmission based on the energy levels of the nodes along the path, avoiding nodes with low energy levels to prevent energy depletion using equation 9.
8. Transmission power adjustment:
   i. Adjust the transmission power of a node based on the distance to the receiver and the path loss exponent, optimizing the power level to minimize energy consumption while maintaining reliable communication using equation 10.
9. Sleep mode optimization:
   i. Apply equation 11 for the determination of optimal sleep mode duration for each node based on the expected traffic load and the energy level, entering low-power sleep mode during idle periods to conserve energy.
10. Energy-aware load balancing:
    i. Apply equation 12 for load balancing among nodes based on their energy levels, preventing overloaded nodes and distributing the load to conserve energy.
11. Repeat steps 2-10 for each time interval:
    i. Continuously monitor ongoing communication activities, update energy levels, adjust transmission power, optimize sleep mode duration, and balance traffic load based on energy levels.
12. Termination of condition:

i. Terminate the algorithm when a predefined condition, such as a minimum network energy threshold or a maximum network lifetime, is reached.

## 5. SYSTEM IMPLEMENTATION

The EOA was implemented on the MANET as a Smart Energy Efficiency Algorithm (SEEA) using simulation methodology. The toolboxes used for the system implementation are as follows;

1. Communications System Toolbox: This toolbox provides various functions and blocks for modelling and simulating wireless ad hoc networks on MANET.
2. Optimization Toolbox: This toolbox provides the energy-aware optimization algorithms used for optimizing energy consumption in MANETs. It also includes functions that can be used to formulate and solve energy-aware routing problems.
3. Bioinformatics Toolbox: This toolbox provides functions for graph theory and network analysis, which can be used to model and analysed the network topology of a MANET. It includes functions for graph visualization, shortest path algorithms, and connectivity measures.
4. Parallel Computing Toolbox: This toolbox provides functions and tools for parallel computing, which can be used to implement energy-aware algorithms that require intensive computations. It includes functions for parallelizing computations, distributing computations across multiple processors, and managing parallel computing resources.

The parameters used for the simulation are reported Table 1 and the values were informed from the MANET model of Jatinkumar and Hossam (2021).

**Table 1: Simulation Parameters**

| **Values** | **Parameters** |
|---|---|
| Simulation area | 2000+2000m |
| Simulation time | 500s |
| Number of nodes | 100 |
| Media Access Control layer | 802.11b |
| Transport layer | User Datagram Protocol |
| Size of packets | 512byte |
| Transmission range | 150m |
| Mobile node speed | 2m/s |
| Full battery capacity of nodes | 1600mAH |
| Initialization energy of the nodes | 7J |
| Transmission power | 10.0W |
| Receiver power | 10.0W |
| Overhead power | 10.01W |
| Hopmax | Hopmin + 2 |
| | |

## 6. RESULTS AND DISCUSSION

This section presents the result of the MANET with Energy Aware Optimization (EAO) as a SEEA for the improved energy efficiency performance of nodes. To understand the performance of the EOA, the behaviour of the nodes was simulated over 100min of communication considering their energy level in equation 7 and average energy consumed per secondas reported in Table 2.

**Table 2: Result of Node Communication with EOA**

| Time (min) | Energy level (%) | Average energy consumed (Joules/secs) |
|---|---|---|
| 10 | 93.65 | 7.474 |
| 20 | 90.561 | 7.403 |
| 30 | 85.453 | 5.632 |
| 40 | 81.034 | 5.134 |
| 50 | 78.547 | 5.046 |
| 60 | 65.513 | 2.466 |
| 70 | 65.504 | 1.548 |
| 80 | 64.435 | 1.092 |
| 90 | 55.234 | 2.405 |
| 100 | 53.544 | 2.453 |
| Average | 73.3475 | 4.0653 |

In Table 2, the performance of the nodes integrated with EOA was evaluated over 100minutes considering energy level and average energy consumed. In Table 2 the average energy level of the nodes as they degraded over time was reported and the average energy was reported as 73.3475% and 4.0653J/secs. What this result means is that during the operation of the nodes via data exchange, the average energy level of the battery after 100minutes is 73.3475%, and that of the average energy level used by the nodes per second of the process is 4.0653J. The result was further graphically analysed as reported in Figure 1 considering the energy consumed.

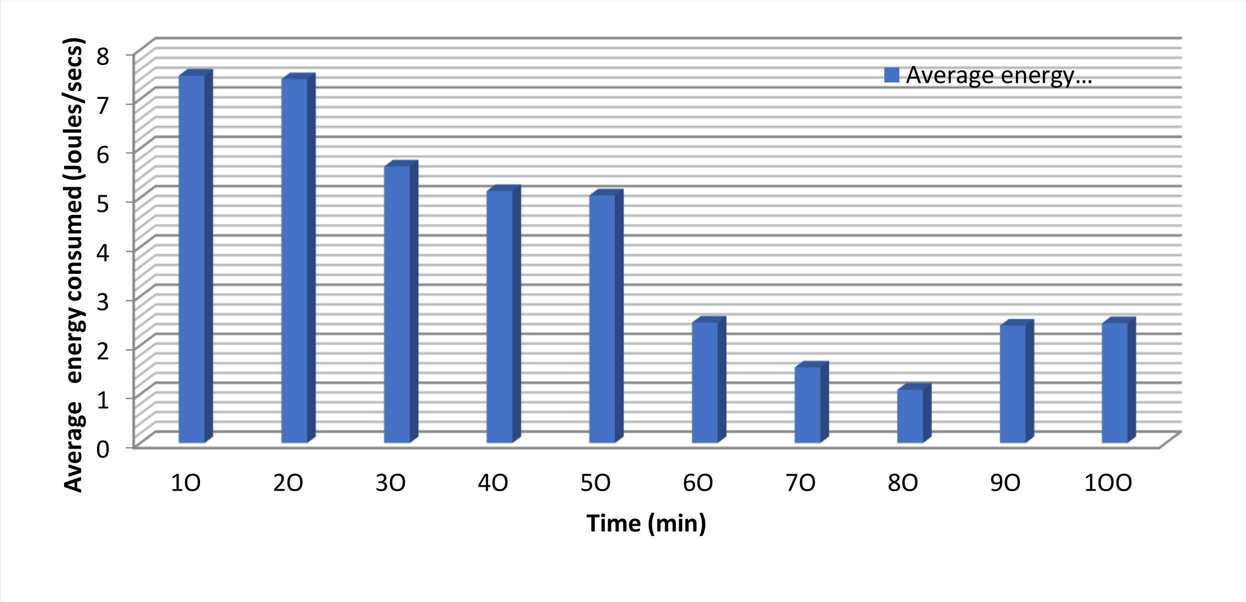


Figure 1: Result of Average Energy Consumed with EOA

From the result of Figure 1, it was observed that the level of energy consumed by the nodes changes over time, the result showed that after 30mins of operation, it became constant and then after 50min, it starts to degrade till 80min and then increased from 90till 100min of the simulations. What happens in thisFigure 1 is that the EOA monitors the behaviour of the nodes considering the communication time and power consumed to determine the energy threshold model in equation 7 and then adjusts the transmission power of the nodes to be able to power the communication process. This is the first reason for the variation in the energy consumed by the nodes over time. The second reason is that when that at 30 to 50min when the energy consumed by the node were constant, it indicated that the nodes were engaged in the same activity over the period, which resultedinan almost a similar amount of energy being consumed. From 50min to 80, when the level of energy consumed drastically drops, this means that at this period, the nodes were idle and the EOA detected it and put the node to sleep, which resulted in the low energy consumed; however, after 80min when incoming signal was received by the nodes, it was awake and engaged in communication which showed why the energy consumed starts to rise from 80 till 100. Similarly, the energy level in Figure 2.

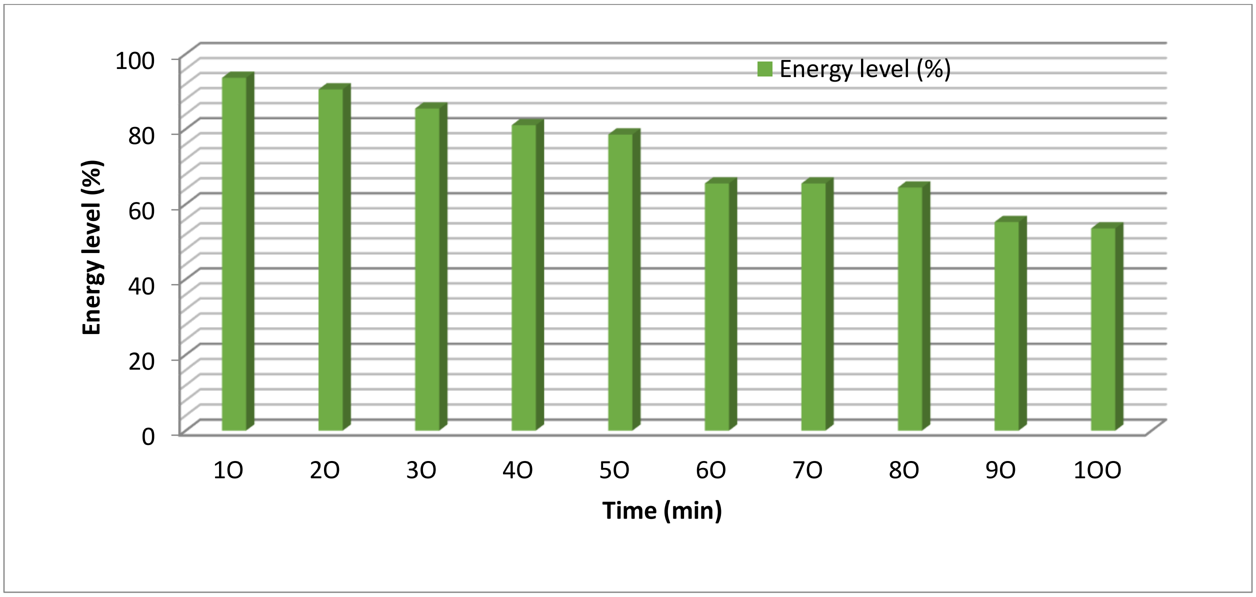


Figure 2: Energy Level of the Nodes Against Time

Figure 2 shows the level of energy degraded by the node batter over the time of communication. From the result, it was observed that while the energy level degrades over time in the communication process, it became constant from 60 to 80min and then degrades from 80 to 100min. The reason was that energy is consumed during transmission and reception of data between nodes, at 60 to 80min, the nodes were idle and the EOA detected it and then put the node to sleep, while monitoring for incoming data from neighbouring nodes, and when data was received after 80min, it starts to degrade again. What this means is that at this degrading point from 80min, the nodes are practically very active, thus resulting to energy level degrade.

### 6.1 Validation of the EOA with MANET

Having evaluated the performance of the EOA over 100 minutes of operation, the result was validated using K-fold cross validation approach (Jason, 2023) which used repetition techniques to test the new system and then determine the average result to report the overall score of the system. To this end, the simulation was repeated 9 other times and all the results including the previous first were reported in the table 3 as 10 iterative test reports;

**Table 3: Validation Result of EOA**

| S/N | Remaining energy level (%) | Energy consumed (J/sec) |
|---|---|---|
| 1 | 73.3475 | 4.0656 |
| 2 | 74.4345 | 4.4454 |
| 3 | 73.4357 | 5.0756 |
| 4 | 73.6560 | 4.4534 |
| 5 | 75.3453 | 4.5722 |
| 6 | 73.5643 | 4.4632 |
| 7 | 74.2325 | 4.5647 |
| 8 | 74.5432 | 4.5745 |
| 9 | 73.4233 | 4.6560 |
| 10 | 73.6543 | 4.0930 |
| Average | 73.96366 | 4.49636 |

Table 3 presented the validation result of the EOA which were integrated as a SEEA to improve energy efficiency and routing performance of nodes in MANET. From the result, it was observed that the average energy level remaining after the simulation stops is 73.96%, energy consumed by the nodes is 4.49636J/s. what this means that averagely the energy level of nodes remaining after 100min of communication within the MANET is 73.96%, with an average energy of 4.49636J/s consumed, implying that the EOA was able to control the rate of energy consumption and make sure that during idle or sleep periods, energy wastage are controlled. More so, comparative analysis with Rule Based Energy Optimization (RBO) technique (Onyiaji, 2024) over 100 minutes of nodes communication was reported in table 4.

**Table 4: Comparative Analysis of Energy Consumption**

| Times | Remaining energy level (%) with RBO | Energy consumed (J/sec) with RBO | Remaining energy level (%) with EOA | Energy consumed (J/sec) with EOA |
|---|---|---|---|---|
| 10 | 49.8475 | 5.3236 | 93.65 | 7.474 |
| 20 | 49.5740 | 5.4093 | 90.561 | 7.403 |
| 30 | 49.4756 | 5.3436 | 85.453 | 5.632 |
| 40 | 48.2656 | 5.6574 | 81.034 | 5.134 |
| 50 | 48.4337 | 4.5366 | 78.547 | 5.046 |
| 60 | 48.5643 | 5.6512 | 65.513 | 2.466 |
| 70 | 48.8925 | 5.4636 | 65.504 | 1.548 |

| | | | | |
|---|---|---|---|---|
| 80 | 49.5012 | 4.5004 | 64.435 | 1.092 |
| 90 | 49.5371 | 5.6545 | 55.234 | 2.405 |
| 100 | 48.6770 | 5.0564 | 53.544 | 2.453 |
| Average | 49.08 | 5.26 | 73.35 | 4.065 |

From the result in table 4, it was observed that the average energy level with RBO is 49.08%, while that with EOA is 73.35%, thus presenting a percentage improvement of 49% decreases in energy level, and also 22.62% decreased in energy consumed per seconds.

## 7. CONCLUSION

This paper has successfully demonstrated the application of EOA for the management of energy in MANET. MATLAB simulation was used to test the algorithms over 100munites nodes communication and the results of the energy level remaining for EOA based node after the simulation is 74%, with 4.06J of energy consumed per second of the communication process. The results of EOA validation reported 73.3475 remaining energy level percentage and 4.4936J/s of energy consumed. Validation of the results reported 4.49636 energy consumed and 73.96366% of energy level. Overall, the result implied that with the integration of the energy-aware algorithm, the EOA algorithm was able to manage the energy consumption rate in MANET nodes for each communication process.

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