An Adaptation of Cuckoo Search Algorithm in Maximizing Energy Efficiency of Dynamic Source Routing Algorithm for Mobile AdHoc Network

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ABSTRACT
The increasing prominence of Mobile Ad-hoc Networks (MANETs) has sparked interest in optimizing their energy consumption to prolong network lifetime and enhance overall efficiency. This study introduces another approach to address this concern through the integration of an energy-efficient routing algorithm and Cuckoo Search Algorithm (CSA). The proposed algorithm aims to optimize the routing paths of Dynamic Source Routing (DSR) within MANETs by leveraging the inherent abilities of the CSA in exploring solution spaces effectively. Traditional routing algorithms often neglect energy consumption considerations, leading to imbalanced energy depletion and reduced network longevity. In response, this study presents a solution that combines the benefits of this proactive routing strategy with the CSA's optimization capabilities. The CSA, inspired by the natural behavior of Cuckoo birds in search of optimal nests, is employed to optimize routing paths based on metrics such as energy consumption, distance, and link stability. The key innovation lies in a synergistic integration which collectively address the trade-off between energy efficiency and network performance. Through simulation and comparative analysis, the proposed algorithm's effectiveness was evaluated against conventional routing algorithm, highlighting its superior performance in terms of energy efficiency, packet delivery ratio, and throughput. Packet loss analysis and transmission count performances were also analyzed for the new paradigm. The results demonstrate that the hybrid algorithm shows a significant level of improvement over the benchmarked algorithm in terms of maintaining energy balance across nodes and prolonging the overall network's operational lifespan. This research contributes to the advancement of energy-efficient MANET routing strategies and opens avenues for future studies focused on incorporating nature-inspired algorithms into networking paradigms for enhanced efficiency and sustainability.

General Terms
Dynamic Source Routing, Routing Algorithm, Energy-Efficient Routing

Keywords
Mobile ad-Hoc Networks, network lifetime, Cuckoo Search Algorithm, network performance.

1. INTRODUCTION
Mobile Ad-hoc Networks (MANETs) are self-configuring, infrastructure-less wireless networks composed of autonomous mobile nodes. They are characterized by their dynamic topology and limited power resources, and frequent node mobility. MANETs have emerged as a vital communication paradigm due to their flexibility and adaptability. They find applications in scenarios where traditional infrastructure-based networks are impractical or unavailable [1]. For their heterogeneous and dynamic nature, common and unpredictable adjustments of network topology do take place always thus leading to complexity in routing a number of cellular nodes on its network. Developing an efficient routing protocol is one of the current research being carried out in this field [2]. To address these challenges, a number of studies were reevaluated entirely based on metaheuristics and deterministic algorithms. Metaheuristics' reputation is constantly expanding as a result of their efficiency and ability to solve challenging challenges. On the other hand, approximation deterministic methods are said to be inaccurate and inconclusive, which frequently results in cases being caught in close optimal [3].

One of the issues in routing in MANETs in energy efficiency. This is because the nodes operate on limited battery power, making energy conservation a pivotal aspect for extending the network's operational lifetime. The dynamic nature of resources as well as their heterogeneity has led to the complexity of resource allocation in the MANET network. Traditional routing algorithms and techniques were not adequate enough for addressing the issues of resource allocation as they were based on multi-path tethering technology with distributed nature whose results were not guaranteed to be optimal. Though traditional routing protocols for MANETs are effective in establishing communication paths, they often neglect the energy consumption aspect, leading to uneven energy depletion among nodes and, consequently, network degradation. These can result in certain nodes becoming incapacitated earlier than others, leading to network partitions and reduced overall network functionality [4]. These can also lead to broken links and routing loops, which can further decrease the efficiency of the network. Thus, there is a need for an energy-efficient routing algorithm in MANETs that effectively balances the energy consumption of the nodes with the communication needs of the network, reduces the likelihood of routing loops and broken links, and prolongs the lifetime of the network. Efforts have been made to design energy-efficient routing protocols for MANETs. Many of the approaches to develop energy efficient routing protocols focus on either optimizing routing paths without considering energy consumption or attempting to minimize energy consumption without adequately addressing the routing efficiency. In order to strike a balance between these two crucial factors, there is a need for innovative routing algorithms that not only optimize paths but also take into account the energy limitations of nodes. The study proposes an approach that leverages the Cuckoo Search Algorithm (CSA) to enhance the energy efficiency of routing in MANETs. The CSA is a nature-inspired optimization algorithm that mimics the breeding behavior of cuckoo birds to find optimal solutions in complex search spaces. By integrating CSA, the resulting Improved Energy Efficient Routing Algorithm (IEERA), provides a comprehensive solution to the energy-efficient routing problem in MANETs.

The study makes significant contributions to the field through the following key points:

i. Improved Dynamic Cuckoo Search Energy-Efficient Routing Algorithm: The research introduces an enhanced dynamic cuckoo search-based routing algorithm that tackles previously identified limitations. This algorithm incorporates energy-aware mechanisms across various aspects of routing, including route discovery, route caching, route maintenance, load balancing, and packet forwarding. The improvements aim to optimize energy efficiency in Mobile Ad-hoc Networks (MANETs) and overcome challenges associated with existing routing algorithms.

ii. Minimization of Node Energy Consumption: One of the primary objectives of the study is to minimize the energy consumption of nodes while maintaining effective communication within the network. By focusing on energy efficiency, the proposed algorithm contributes to prolonging the operational lifespan of nodes, which is crucial for the overall sustainability and performance of MANETs.

iii. Reduction of Routing Loops and Broken Links: The research addresses the critical issues of routing loops and broken links in MANETs. By implementing robust mechanisms, the proposed algorithm aims to decrease the likelihood of these problems occurring. This, in turn, enhances the reliability of routing in MANETs, ensuring a more stable and dependable communication infrastructure.

In summary, the study presents an advanced routing algorithm that not only improves energy efficiency but also enhances the overall reliability and robustness of routing in dynamic MANET environments.

2. REVIEW OF RELATED WORKS

As outlined by Kaur and Gurm [5], a Mobile Ad-hoc Network (MANET) is characterized as a wireless ad-hoc network devoid of infrastructure, where mobile nodes establish communication through wireless links, eliminating the need for a base station or access point. MANET possesses distinctive features like minimal infrastructure, decentralized control, and a dynamic topology. Routing in MANET presents challenges due to the constant mobility of nodes, leading to dynamic topology changes, occasional route failures, and subsequent degradation in network performance. The Cuckoo Search Optimization (CSO) algorithm emerges as a promising technique for devising efficient routing protocols in MANET. This artificial intelligence optimization algorithm is particularly adept at determining the shortest route for data transmission within MANET. In their study, Kaur and Gurm delved into routing protocols such as AODV and DYMO, alongside the application of the CSO algorithm. Notably, they implemented the CSO algorithm on AODV and DYMO protocols using the NS2 emulator, enabling a comparison of emulator results with the conventional AODV and DYMO protocols.

In their work, Sekhar and Prasad [6] introduced a Cuckoo Search algorithm to address misdirected adversaries in multi-hop routing within Mobile Ad-hoc Networks (MANETs). They proposed a robust, reliable, predictive routing framework incorporating an optimized selection of cluster heads to enhance the efficiency of routing in MANETs. The clustering technique embedded in this framework aimed at streamlining the routing process. The heavy workload on a node leading to a drop in power for the group leader triggered a regrouping of the cluster, necessitating the selection of a new leader to prevent packet loss during data transmission. However, the process of re-clustering had drawbacks, reducing overall routing efficiency and increasing processing time. To tackle this, the Cuckoo Search-based optimization algorithm was introduced to solve the clustering problem. It involved selecting a secondary cluster head from the initially formed cluster group, eliminating the need for re-clustering.

The proposed framework enables nodes to choose a secure and reliable route in MANET, and its performance is evaluated by comparing simulation results with the AODV routing protocol. The comparison demonstrates a significant enhancement in the performance of the proposed routing protocol. Mandhare et al. [7] explored the Quality of Service (QoS) performance in Mobile Ad-hoc Networks (MANET) through the introduction of the CSO-AODV protocol. This protocol achieves QoS by collaboratively determining the Reliable Route Path Length Yield (RRP LY) from multiple paths through a best-fit calculation, thereby ensuring QoS constraints during route discovery. The performance evaluation of the proposed protocol was conducted through network simulation, and the outcomes were compared against the ACO, PSO, and AODV protocols. The evaluation involved analyzing results under three distinct conditions: mobility, scalability, and congestion. The findings indicate that the proposed CSO-AODV protocol is effective in handling network mobility, scalability, and congestion, demonstrating its ability to provide stringent QoS for various applications. In future work, the researchers express the intention to enhance the robustness of their proposed system by modifying the cuckoo search algorithm.

In their study, Gopalan and Radhakrishnan [8] introduced a routing algorithm based on the Improved Cuckoo Search Optimization (ICSO) to address power and latency challenges, particularly in applications related to rescue and emergency scenarios. The proposed system involves the optimal clustering of Mobile Ad-hoc Network (MANET) nodes, where the cluster leader selection process is executed using the enhanced LEACH protocol (I-LEACH). Once the Cluster Head (CH) has been chosen, both intra- and inter-cluster communication are established. The ICSO algorithm is then employed to determine energy-efficient and latency-sensitive shortest paths.

This routing approach aims to specify paths that prioritize energy efficiency and minimal latency while concurrently mitigating security threats from various attacks. Survey results indicate that the energy delay-aware routing system designed by ICSO provides efficient routing with improved performance in rescue and emergency applications. The improvements are observed in terms of distribution speed, packet distribution, bandwidth, end-to-end latency, power usage, throughput, and network lifetime, thereby enhancing the overall system consistency.

Khabiri and Ghaffari [9], routing description based on energy-aware clustering in WSN using cuckoo optimization algorithm. This work uses cuckoo improvement calculus, a proposed energy-conscious clustering control convention for wireless sensor networks that can cluster the system and select the ideal cluster head. The proposed technique has considered about four conditions to select cluster heads in cuckoo orientation calculation, precisely the residual energy of the nodes, base sink splitting, inner group splitting and group separation. The results of recreating the proposed strategy in Matlab conditions show that it outperforms other computations, for example, LEACH, low energy explicit application, LEACH-EP and LEACH with edge based large dead splits and packet delivery rates in six different scenarios.

In their study, Kout et al. [10] introduced a novel reactive routing protocol based on a biologically inspired method known as cuckoo search. This method is asserted to be more powerful compared to other existing methods. The study was conducted in two phases: the first involved implementing their method, and the second focused on creating a simulation scenario to test and evaluate their routing protocol. The AODV, DSDV, and AODV AntHocNet routing protocols were used for comparison.

The specific protocol introduced, AODVCS, demonstrated greater efficiency than the others in terms of two performance metrics, End-to-End Delay (E2ED) and Packet Delivery Ratio (PDR). The researchers proposed the conduct of additional complex simulations using other mobile models. Furthermore, they suggested that their protocol could be generalized to other ad hoc networks, including Vehicle Ad hoc Networks (VANET) and Flight Ad hoc Networks (FANET). This indicates the potential versatility and applicability of their proposed cuckoo search-based routing protocol beyond the initial scenario studied.

In Tabatabaei's study [11], a novel routing protocol was introduced to enhance power consumption efficiency, utilizing the Cuckoo Optimization Algorithm and the TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) multi-criteria algorithm. The proposed method is designed to operate in a dynamic environment, considering four important variables: accessible bandwidth, remaining power, travel speed, and the number of steps required for routing.

To select suitable groups for forwarding data packets, the TOPSIS multi-criteria algorithm was employed. Simultaneously, the Cuckoo Optimization Algorithm was used to determine the shortest route between the transition groups. Simulation results demonstrated that the combined approach of selecting a stable route through the Cuckoo Optimization Algorithm and the TOPSIS algorithm significantly impacted network performance. The proposed algorithm exhibited superior performance compared to other methods, showcasing improvements in end-to-end throughput and latency. Additionally, Dharma was introduced by Tabatabaei and Behravesh as part of the study, contributing to the evaluation of end-to-end throughput and latency in the proposed algorithm.

In their work, Mohan and Ananthula [12] tackled security issues within Mobile Ad-hoc Networks (MANET) by introducing an optimization algorithm named Jaya Cuckoo Search (JCS). This algorithm combines the Jaya algorithm with the Cuckoo Search (CS) algorithm to establish secure routes among MANET nodes, ensuring both feasibility and security. The JCS algorithm incorporates a fitness function that employs a multi-objective approach, considering parameters like distance, link lifetime, delay, energy, trust, and reputation factor to identify a secured path. The proposed algorithm assesses the optimal path based on Quality of Service (QoS) parameters, including energy, link lifetime, delay, reputation factor, trust, and distance. The security evaluation involves selecting paths that exhibit superior energy efficiency, longer link lifetime, reduced delay, shorter distance, higher trust, and a greater reputation factor. However, there is an opportunity to enhance the QoS parameters by refining the cuckoo search algorithm. This refinement could lead to a reduction in energy consumption, decreased packet loss, and improvements in both packet delivery ratio and throughput.

3. METHODOLOGY

The model adopted is the pathway mobility model, which is generated in the form of a graph denoted by G, having buildings in the form of vertices, V and set of edges, E, model the streets and freeways between those buildings.

$$G= (V, E) \quad (1)$$

The associated graph in this context can be either generated randomly or carefully defined, depending on the requirements of the network simulation. Mobile nodes are positioned along the edges of the graph. Each node randomly selects a destination, and its route progresses toward this destination by following the shortest path along the edges. Upon reaching the destination, the node pauses for a specified pause time (T_{pause}) and subsequently selects the next destination for its next movement, employing the same algorithm. This cyclical process continues until the simulation concludes. Notably, in this model, mobile nodes are constrained to move exclusively along pathways. The nodes travel in a pseudo-random manner on these pathways, introducing a certain level of randomness into their movements. In a Mobile Ad-hoc Network (MANET), when a request is initiated from a source node to a destination, the node identifies its neighboring nodes using the neighbor table stored in the route cache. Subsequently, it explores the shortest paths for transmitting the packet from the source to the destination among all neighboring nodes listed in the route cache. The algorithm evaluates these paths and selects the one characterized by energy-efficient nodes, aiming to enhance Packet Delivery Ratio (PDR), Throughput, and minimize packet loss. Following the selection process, the source node transmits the packets through the chosen shortest path with the most efficient energy utilization to reach the destination. This approach diverges from the conventional method of broadcasting from a dynamic source, leading to improvements in network performance and efficiency. For instance, as illustrated in Figure 1, the optimal routes from the source node to the destination involve nodes <1>, <6>, <10>, <15> and <1>, <5>, <8>, <15>. These paths represent the most efficient ways to transmit the packet, with one of them exhibiting superior energy efficiency, resulting in minimal or no packet loss during transmission. This methodology differs from existing algorithms that traditionally focus solely on distance or energy efficiency when searching for optimal paths. only. Figure 2 shows the overall algorithm of the system.

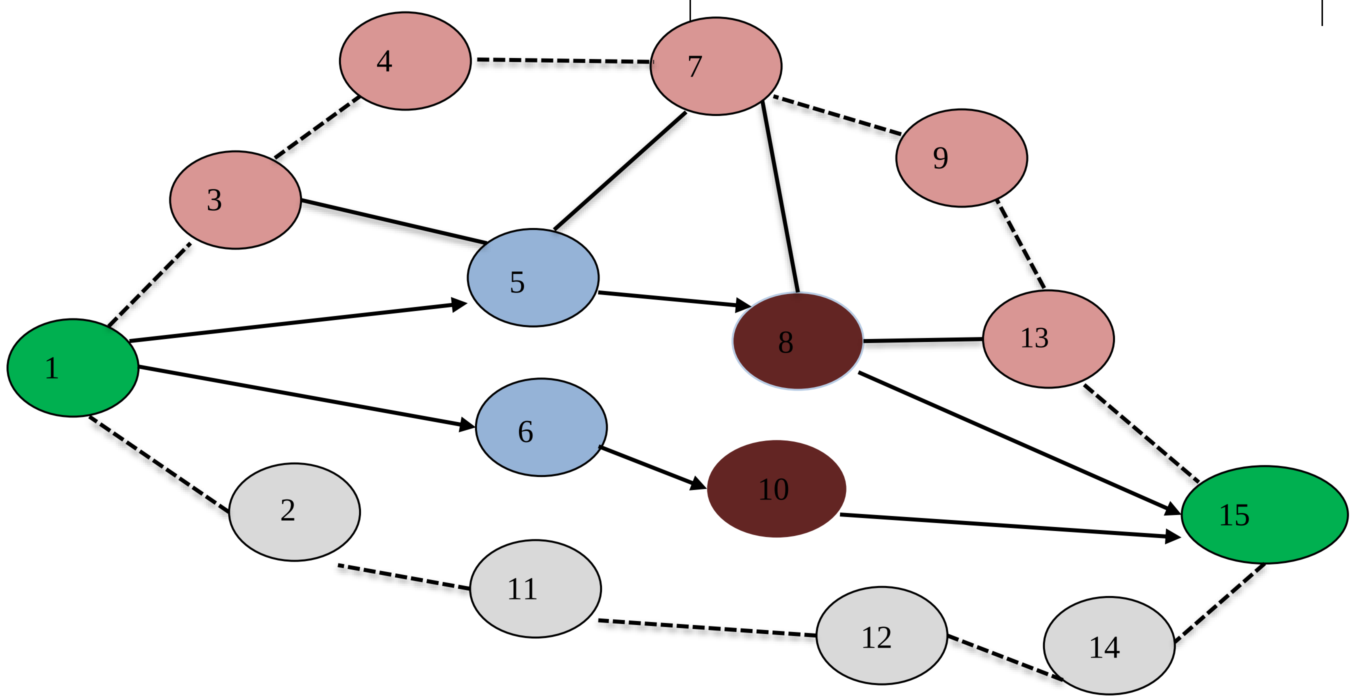

Figure 1: Architecture of the Proposed model

Represents Shortest Path

Represents Short Path

Represents the Long path

Begin

Input: Advanced nodes (Nn)

Output: Construct an optimal path between Nn and NF

1: Initialize λkj

Qs_a and $a \leftarrow 1$

2: While termination conditions are not met do

3: $a \leftarrow a + 1$

4: for $k = 1$ to K

5: k is positioned at FL

6: $F(k) \leftarrow FL$

8: $Rk \leftarrow \emptyset$; $\varphi k \leftarrow \emptyset$

9: While $F(k) \neq FL$ do

10: if C($F(k)$) - $\varphi k \neq \emptyset$ then

11: Choose ($F(j)$ from C($F(k)$) - φk

12: $Rk \leftarrow Rk\cup\{F(i)\}$; $\varphi k \leftarrow \varphi k\cup\{F(i)\}$; $k \leftarrow$ j

13: else

14: Back to the previous-hop of $F(k)$

15: end if

16: end while

18: Determine the value of ZO

Qs_a using equation (26)

19: end for

20: Update the number of pheromone values

21: Compare the values of solutions obtained

22: end while

23: Return the optimal solution

24: Choose the best solution as the output

25: End

Figure 2: The Improved Cuckoo Search Algorithm

3.1 Formulation of Mathematical Model

A mathematical model was developed using a shortest-path approach. In this model, a directed graph G = (M, N) is defined, with M representing a set of nodes and N representing a set of arcs in the graph. The objective of the shortest-path problem is to identify a path with the minimum distance between two nodes, denoted as s (source or starting) and t (target or destination). The cardinalities of sets M and N are expressed as parameters a and b, respectively. A path is defined as a sequence of nodes m1, . . ., mk, and is considered elementary if no node is visited more than once.

Let δ+(i) and δ−(i) represent sets of arcs leaving and entering node i ∈ M, and let N(S) be a set of arcs with both ends in S ⊆ M.

Indices, parameters, and decision variables are presented as follows:

Indices

i, j, and k: indices representing nodes in G

N: a set of arcs from G

Parameters

cij: distance from node i to j, (i, j) ∈ N

Z: the total distance

Decision variables

xij is equals to 1 if (i,j) is chosen and 0 otherwise.

The objective function and constraints for the shortest-path problem are presented next.

$$Z = \min \sum_{(i,j)\epsilon N} C_{i,j} x_{i,j} \quad (2)$$

$$\sum_{K\epsilon\delta+(i)} x_{ki} = 1, i = s \quad (3)$$

$$\sum_{K\epsilon\delta+(i)} x_{ki} - \sum_{K\epsilon\delta+(i)} \quad (4)$$

$$\sum_{K\epsilon\delta+(i)} x_{ki} - \sum_{K\epsilon\delta+(i)} x_{ki\,=-1,\ i=t} \quad (5)$$

$$X_{i,j} > 0\ for\ (i,j) \in N, x \in\ Z^{|N|}.$$

The objective function is represented by Equation (2), where the total distance is minimized.

Equations (3) and (5) represent the net flow at nodes s and t, where the net flow at node s is 1, and the net flow at node t is −1. The flow conservation constraints for nodes other that s and t are represented by Equation (4). When applying a shortest-path model for determining a solution for a dynamic route-planning problem with energy efficiency, the distance (cij) associated with each path segment (defined by (i,j)) that contains an obstacle and cannot be used is set to a large value that is based on the size of the transportation area. If there exists a feasible solution, the segments with large cost values are not selected in the optimal solution.

3.2 Experimental Setup and Evaluation Metrics

The result below are outcomes of the simulations of the energy efficient Dynamic Source Routing (DSR) algorithm in MANET. The algorithm was simulated on nodes 20, 40, 60, 80 and 100. The experiment was carried out five times for each number of nodes and the arithmetic mean computed. Table 1 shows the experimental parameters setup during simulation.

The simulated results of performance metrics are as follows:

i. Energy Efficiency: It is also the percentage of energy conserved to perform the same task or produce the same result.

Table 1: Simulation Parameters

Simulation Parameter	Value
Simulation time	1000 s
No. of Nodes	20, 40, 60, 80 and 100 nodes
Simulation Area	1000m* 1000m
Mobility model	Random Way point
Network Layer Protocol	TCP
Traffic Model	CBR
Transmission Range	250 m
Size of the Packet	512 bytes

ii. **Packet Delivery Ratio (PDR):** PDR compares the number of packets successfully received by the destination node (Rni) with the total number of packages sent by the source node (Sni). PDR serves to measure the success of the delivery ratio. The higher the PDR value, the better the network performance. PDR is one of the QoS parameters. It indicates the success rate of a routing protocol and can be calculated using Equation (1):

$$\text{PDR} = \frac{(\sum_{i=0}^{N} Rni)}{(\sum_{i=0}^{N} Sni)} \quad (6)$$

iii. **Throughput:** is the data's effective transfer rate, whereas it is measured in bytes per second (Bps). Throughput is the total number of successful packet arrivals observed on the destination device over a certain time interval divided by the duration of the time interval. The main aspect of throughput is knowing the availability of sufficient bandwidth for the application. This determines the amount of traffic an application can receive when it passes through the network. This throughput can be measured after the data transmission occurs and can be calculated using Equation (2):

$$\text{Throughput} = \frac{Total\ of\ the\ Packet\ Sent}{Total\ Data\ Sending\ Time} \quad (7)$$

iv. Packet Loss: the percentage of packets lost is the total number of packets sent over the network in proportion to time. If packet loss occurs in the TCP protocol, it will send the lost packet again, resulting in increased overhead in terms of energy wasted to forward a dropped packet. The UDP protocol, however, does not resend a lost packet, which causes packet loss. Several things cause the loss of packets on the network, including network overload, corruption of the packet, errors in physical media problems, and the failure of the receiver's transmission (i.e., buffer overload). Packet loss can be calculated using Equation (3):

$$\text{Packet Loss} = \frac{Total\ of\ Packet\ Sent - Total\ of\ the\ Packet\ Received}{Total\ of\ the\ Packet\ Sent} \quad (8)$$

v. Transmission count: Measure of the quality of a path between two nodes in a wireless data network.it is the number of transmissions of a packet necessary for it to be received without error at its destination.

3.2.1 Energy Efficiency

The graph below (Figure 3) shows the relationship between the energy efficiency and the number of nodes. It shows that the energy efficiency increases as the number of nodes increase except at nodes above 60 where it begins to decline. This implies that the energy of the nodes is increasingly conserved as the nodes increase. The average energy conserved was 38.94 for this paradigm, as against 27.83 for the benchmarked scheme, a 39.92% increase the energy efficiency.

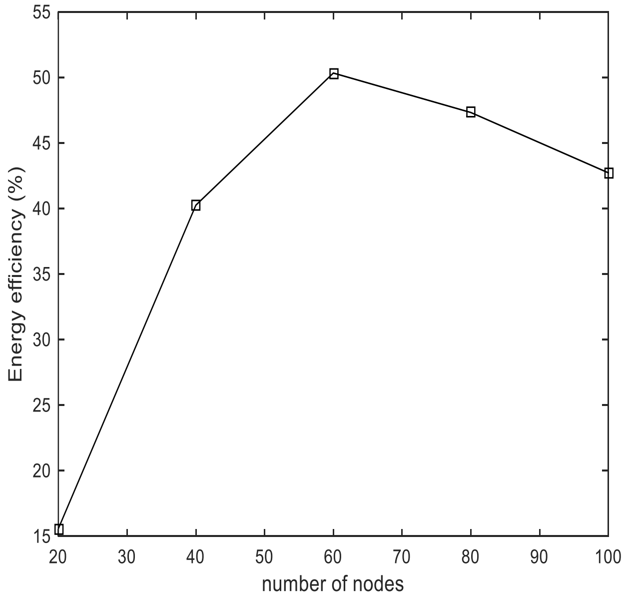

Figure 3: Graph of Energy Efficiency Against the Number of Nodes for the Improved Algorithm

3.2.2 *Packet delivery ratio*

Figure 4 shows the relationship between packet delivery ratio and the number of nodes. It was observed that though the ratio increases significantly generally, there was a drop from nodes above 40. The average ratio for the nodes was 0.70 against 063 for the Energy Efficient DSR paradigm, a 11.11% increase.

3.2.3 Throughput

In figure 5, it shows that the throughput increases as the nodes increase up to 60 nodes and began to decline. However, the overall throughput improved by 14.55% from 0.55 on the Energy efficient DSR against 0.63 on the proposed algorithm.

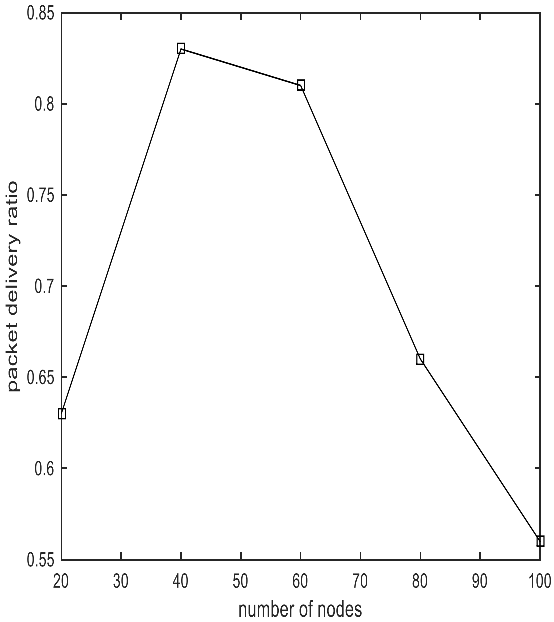

Figure 4: Graph of Packet Delivery Ratio Against Number of Nodes for the Improved Algorithm

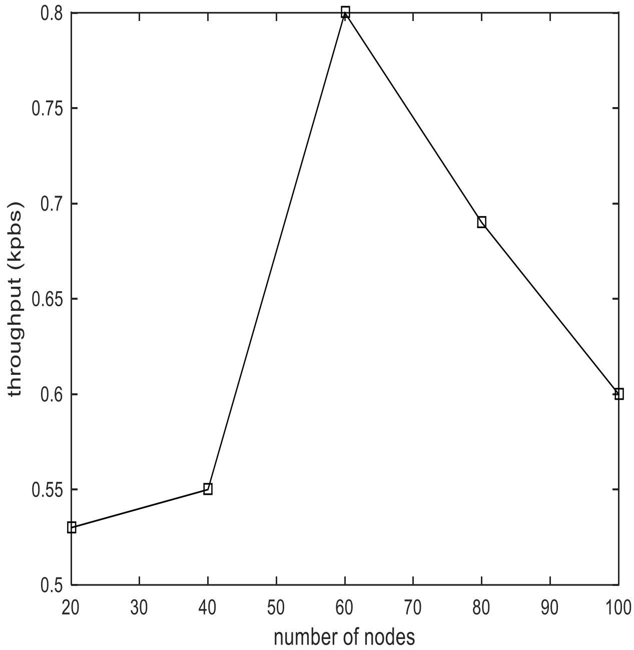

Figure 5: Graph of Throughput Against Number of Nodes for the Improved Algorithm

3.2.4 *Packet loss*

Figure 6 shows the graph of packet loss with increasing number of nodes. The packet loss increased from node 20 to 40 and began to decrease. This shows that the packet loss generally decreases as the number of nodes increase. The average packet loss was 0.20.

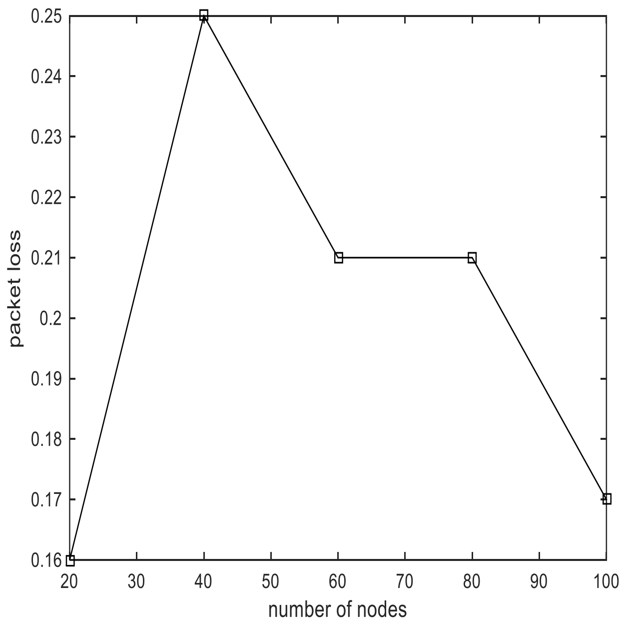

Figure 6: Graph of Packet Loss Against the Number of Nodes for the Improved Algorithm

3.2.5 *Transmission Count*

The graph of transmission count compared with the number of nodes shows an increase up to 60 nodes and then a linear decline. The average transmission count was 0.69. See Figure 7.

3.3 Comparative Analysis Between the Existing EEDSR Techniques and the IEEDSR.

Table 2 shows the result of the average performance obtained from previous the previous energy efficient DSR routing algorithm (EEDSR) and the improved dynamic source routing (IEEDSR).

Table 2: Performance Comparison between EEDSR and IEEDSR

Parameters	EEDSR	IEEDSR	% improvement
Energy	27.83	38.94	39.92
PDR	0.63	0.70	11.11
Throughput	0.55	0.63	14.55
Packet Loss	-	0.20	-
Transmission Count	-	0.69	-

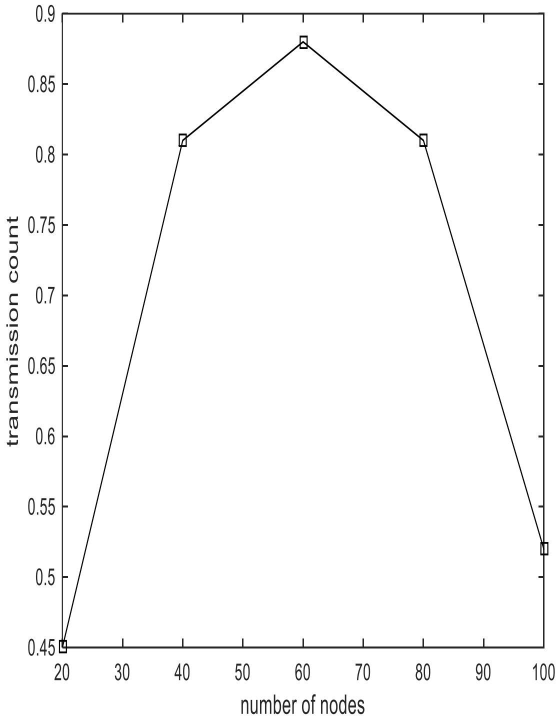

Figure 7: Graph of Transmission Count Against the Number of Nodes for the Improved Algorithm

4. CONCLUSION AND RECOMMENDATION FOR FUTURE WORKS

This study developed and simulated an improved routing protocol formulated on the cuckoo search algorithm which is inspired by the breeding strategy of cuckoos. Performance analysis of the IEEDSR in MANET was carried out by varying number of nodes ranging from 20-100 nodes. The comparative study of the proposed techniques showed that the IEEDSR has a significant improvement over the EEDSR with respect to energy consumption efficiency, throughput, and packet delivery ratio. Hence, the study concluded that the implemented improved dynamic source routing technique performs better than the traditional energy efficient. The new algorithm has addressed the problem of poor performance on the energy, throughput, and packet delivery ratio. However, further study should be carried out to determine the end-to-end delay as well as other performance metrics as well as optimize the algorithm. There is also a need to improve on the efficiency of the algorithm on a higher number of nodes. This was as a result of the observation made from the simulation of degradation of performance from 60 nodes and above. We also recommend extensive evaluation of this approach by considering various datasets or real life scenarios which would undoubtedly enhance this research.

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