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Energy-Efficient Routing Protocol Using Fuzzy and Kangaroo Optimization Techniques in Iot-WSN Environment

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Abstract
Wireless Sensor Networks (WSNs) are essential building blocks for effective data collection and communication in Internet of Things (IoT), which is a dynamic network of linked devices. Critical issues, which is affect network lifetime and dependability include imbalanced network loads, inefficient data routing, and restricted energy resources for IoT-assisted WSNs. To address this this research proposes a unique fuzzy-based intelligent clustering and efficient routing method. To ensure balanced energy consumption and efficient cluster formation, the proposed model uses a fuzzy logic-driven clustering technique to pick the best Cluster Heads (CHs) based on a number of factors, such as residual energy, node centrality, and closeness to neighbors. A Kangaroo Optimization Algorithm (KOA)-based routing technique is presented for effective data forwarding by selecting best transmission paths by taking into account the energy metrics. The routing decision process includes a fitness function designed to conserve energy while maintaining dependable and low-latency communication. Extensive simulation results confirm that proposed approach significantly improves energy efficiency, throughput, Packet Delivery Ratio (PDR) and enhances overall performance compared to conventional methods.

Keywords: Wireless Sensor Network, Internet of Things, Cluster Heads, Kangaroo Optimization Algorithm, Energy Consumption, Throughput, PDR.

1. Introduction

WSN is made up of various sensor nodes with inadequate energy, storage, and processing power. By connecting through WSNs, the IoTs have a vital technical vision in realizing the goal of environment. Large-scale WSNs require path effectiveness, flexibility, and scaling mobility assistance, and a protocol for routing with minimal overhead [1]. As a result, current protocols for portable, wired, and sensor networks have been designed specially to increase effectiveness of IoT-based networks owing to power of several systems, such as small devices and large household appliances [2]. Everyday actions involve a variety of devices, including computers, smartphones, sensors, and home appliances like air conditioners, refrigerators, microwaves, coffee makers, and washing machines. All of these tasks are monitored and recorded by the IoT [3]. Whereas, WSN is a group of sensors associated via a wireless media [4].

Additionally, base station in charge of running the WSN system, which also acted as the sensor devices' [5]. The present sensor output directly affects the WSNs operate. However, noise from both internal and external sources primarily affects WSN sensors [6]. IoT-WSN is used to collect data in the arena, monitor animal footprints, analyse pollution levels, and prediction the existence of forest fires and rubbles flows, among other environmental monitoring and protection tasks [7]. Additionally, to connect the sensor nodes in WSN, sensor nodes are separated by the maximum distance, and low-power wireless channels are used. Data produced through sensor needs appropriate authentication procedures to avoid security problems and data manipulation [8-9].

The clusters used to deliver efficient data transmission and bound energy use in the IoT-WSN environment. An existing methods, Energy-Efficient Hybrid Clustering Technique (EEHCT) is designed for IoT-based WSN achieve longevity of network. Nevertheless, dynamic clustering regularly changes clusters, requiring more energy even when the clusters are stable. Furthermore, the dynamic installation during the initial stage requires additional modifications to perform well [10]. K-Means clustering for WSNs delivers a communication distance reduction between each node, further extending the overall network lifetime. The downside of K-Means is its sensitivity to the initial placement of centroid, particularly for the first set of clusters result unbalancing clusters. Further, in a heterogeneous network, cluster imbalance an additional restricting performance factor [11]. Low-Energy Adaptive Clustering Hierarchy (LEACH) encompass the lifespan of sensor nodes that are distributed within clusters in WSN. LEACH provides dispersed operation and energy economy for WSN. However, it have unequal cluster distribution and the possibility of cluster head failure [12]. Also, routing is used to describe the determination of most energy-efficient path for data transmission between the sensor nodes and the base station in the IoT-WSN environment.

Optimization technique such as a hybrid Fuzzy-logic and a Quantum Annealing algorithm-based routing protocol (FQA) improve constancy of network and minimalize energy consumption. FQA have higher energy, better throughput, and maximum alive node. However, high delay and high computational complexity when using FQA [13]. Whereas, Particle Swarm Optimization (PSO)-based routing is used to find routing path and improved efficiency. Also, PSO have great throughput, improves throughput of network. Nonetheless, it have high end- to- end delay, low convergence rate and computational complexity [14]. Moreover, BAT-based routing to enhance data transmission efficiency. It is ease of use, simplicity, and quick convergence. Nevertheless, possibility of immobility, restrictions on exploration capacity, and challenges striking a balance between exploration and extraction [15].

To address the limitations of the existing methods, this study employs a fuzzy logic-based clustering and KOA based routing protocol to attain balanced energy consumption, effective clusters, and optimal paths for data transmission in IoT-WSN systems.

Related work

Shuang Wang (2021) [16] have presented Genetic Algorithm (GA) in WSNs to make high fault toleran ce for data routing and low-cost energy consumption. The routing method is optimization of routing paths by multiple parameters, distance of nodes, energy levels, and hops for data transmission, it ultimately streams data using low energy. However, the routing method computational resources tend to be significantly higher when performing various genetic operations. Therefore, real-time data collections or transmissions slow down due to the high costs of processing and high energy consumption.

Ramanpreet Kaur *et al* (2025) [17] have implemented Flower Pollination Algorithm (FPA) is an energy efficient routing method used to improve the life of a WSN by selecting the highest quality nodes for data transmission processed over distance and energy usage. FPA's smartly optimize routes between the nodes based on energy cost, and average neighbour distance from the community which improved packet delivery and packet loss, and substantially reduced energy costs. Furthermore, it is crucial for avoiding overloading systems and to maintain radio-free real-time implementation, which is more difficult in highly dynamic environments.

Abdulmalik Adil Abdulzahra *et al* (2022) [18] have developed Bacterial Foraging Optimization Routing Protocol (BFORP) to data transferred efficiently using far less energy by employing different paths on a WS node based on the routing efficiency costs, traffic load, and proximity between the sink and other nodes. By reducing overall energy consumption BFORP improved network lifetime by avoiding delays in routing packets. Nevertheless, BFORP has greater computational complexit, which leads to longer processing times.

J. Jerlin Adaikala Sundari *et al* (2024) [19] have introduced Energizing Firefly Optimization-Inspired Routing Protocol (EFOIRP) is designed to increase data transmission in WSN based on IoT with clustering and routing approaches. Its intelligently navigate physical barriers by avoiding interference and delay when possible for consistent data transmission while saving energy. EFOIRP reduces interference between signal transmissions and improves data transmission efficiency, but the different levels of obstructions limited on a route and scalability of the network affect its performance.

Zhiqun Wang *et al* (2023) [20] have employed Binary Gray Wolf Optimization (BGWO) routing and fuzzy logic- clustering manage energy consumption and delay in IoT networks. The BGWO approach improves energy consumption while also selecting the best parent node for decision-making which improves the stability and lifetime of the networks. Although the BGWO reduces delay and energy consumption, it’s increased computational costs, which problematic for IoT devices operating with limited resources and constrained environments.

The major contributions of the proposed work involves

- To utilized IoT systems using WSNs to ensure efficient, scalable data communication.
- Fuzzy logic clustering used to intelligently choose the CH according to residual energy of the nodes, and proximity to neighbour node.
- KOA routing protocol implemented to find the shortest paths and allow energy efficient data routing.

2. Proposed work

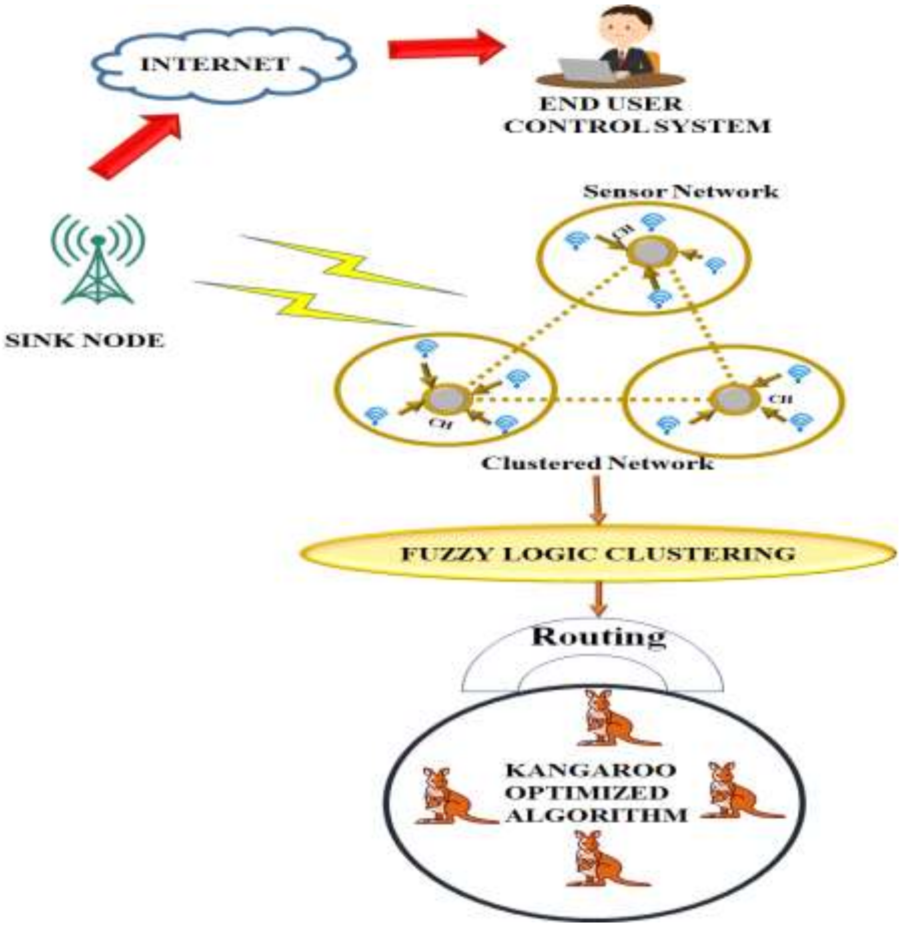

Figure 1. Proposed block diagram

The approach that we are presenting can be seen in Figure 1. The nodes of the sensors encompass a clustered network based on fuzzy logic clustering. The routing process is managed by the KOA, which ensures data is transferred from the sink node to the end-user control system of the Internet efficiently. To ensure balanced energy consumption and efficient cluster formation, the model uses a fuzzy logic-driven clustering technique to pick the best CHs based on a number of factors, such as residual energy, node centrality, and closeness to neighbours. KOA-based routing technique is presented for effective data forwarding by selecting best transmission paths by taking into account the energy metrics. The routing decision process includes a fitness function designed to conserve energy while maintaining dependable and low-latency communication. The proposed KOA approach significantly improves energy efficiency, prolongs network lifetime, and enhances overall performance.

A. Fuzzy logic Clustering

CH selection

The fuzzy logic to intelligently identify appropriate CHs by considering multiple criteria at once because of fuzzy logic's flexibility and tolerance to uncertainty. Suitable membership functions and fuzzy rules are defined in the direction of comprehensively assess eligibility of each node for CH selection as shown in Figure 2. Every round base station gathers relevant data from all nodes in network and uses a fine-tuned fuzzy rule set to recognize optimal set of CHs.

Choosing Potential CHs

To increase network efficiency and increase longevity of WSN, nodes with acceptable residual energy are identified as potential CHs, as sensor nodes are running on limited, non-rechargeable energy. Nodes with energy levels equal to or greater than a given threshold are measured as CHs. The set of CHs is given by:

:$S_{CH} = \{N_i / E(N_i) \geq E_{threshold}\}$ (1)

Where$E_{threshold}$ denotes average energy of currently active nodes and $E(N_i)$ denotes node $i's$ residual energy. $E_{threshold}$ represents average residual energy of active nodes in network and its calculated using,

$$E_{threshold} = \frac{\sum_{i=1}^{N_{alive}} E(N_i)}{N_{alive}} \quad (2)$$

Equation (2) signifies nodes with sufficient energy to be designated for CHs. These equations ensure that nodes providing sufficient power to act as CHs are effectively connected, allowing loads to be spread as evenly as possible across the network and improving network stability.

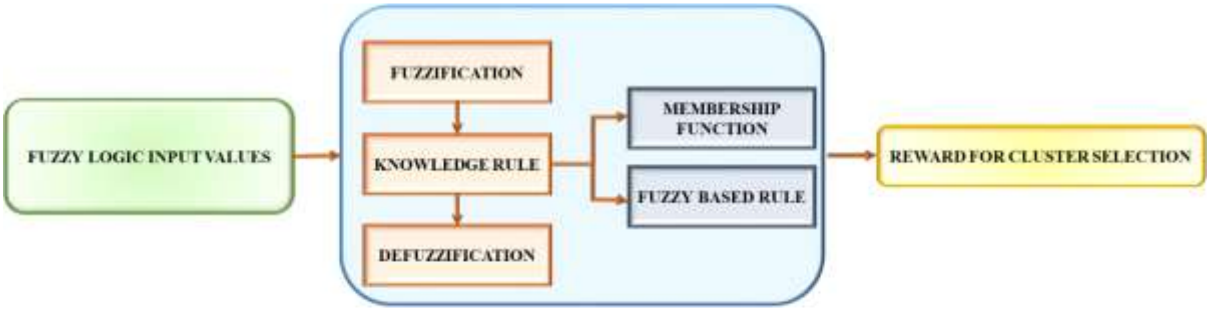

Figure 2. Architecture of Fuzzy logic cluster

Fuzzy logic control

The executed fuzzy logic control model includes a fuzzifier, fuzzy rules, a fuzzy inference engine, and a defuzzifier. This approach involves four steps:

- Fuzzification of input variables, including energy, focus, and centralization– It take crisper inputs of each variables and determine the amount of input belongs to each corresponding fuzzy sets.
- Evaluate rules by applying fuzzy inputs to its antecedent and consequential membership functions.
- Aggregation of rule output is a synthesis of all rules' output.
- Defuzzification involves taking the aggregate output fuzzy set (π) as input and producing a single crisper number as output.

For defuzzification, it identifies the location at which an upward path is required to divide the aggregate set chance between two identical parts. During training, COG (Center of Gravity) is determined and evaluated across a number of locations on combined result of the membership function applying the subsequent equation:

$COG = (\sum \mu_A(x) * x) / \sum \mu_A(x)$ (3)

Here, $\mu_A(x)$ denotes membership function of set A. Fuzzy logic-based clustering is clearly used for selection of optimal CHs allowing for multiple parameters like residual energy, the node's centrality to other nodes, and proximity to neighboring nodes. Further, the optimized routing protocol allows for efficient data packet transmission utilizing energy-aware routes, which is presented below.

B. Kangaroo Optimization Algorithm

The KOA utilized in routing protocols, particularly with respect to optimizing selection routes for ener gy efficiency in WSNs. KOA is effective at exploring the solution space, making it suitable for use in both dynamic and heterogeneous environments in selecting the most optimal path. The kangaroo population is randomly initialized with velocity values from the range {1, 1.5, 2}, and a fitness function is used to get the value of k_{gbest} the algorithm iterates several times. The kangaroos use $N_{iteration}$as an input parameter, and existing iteration is separable by K, they swap out their nodes at random. Every kangaroo from the new node, exchanging information in near local best solutions and this phase involves mutual male kangaroo sniffing to generic kangaroo sniffing in Figure 3.

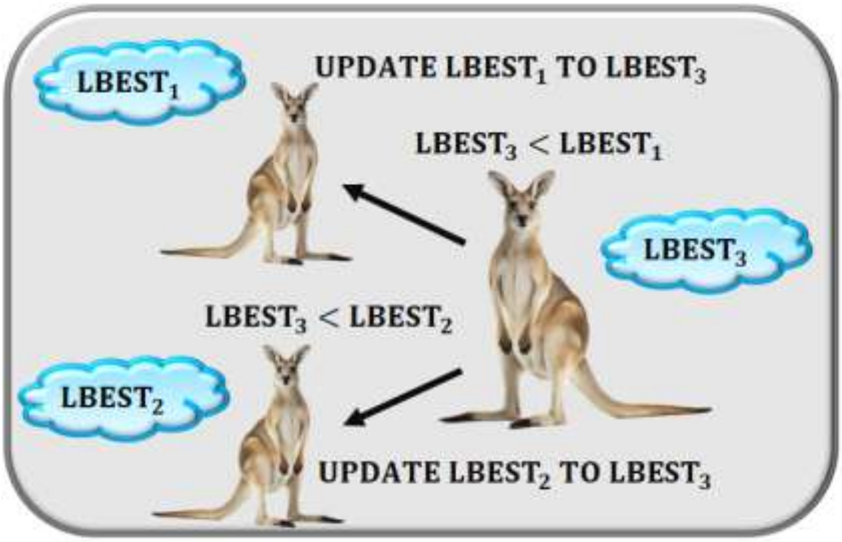

Figure 3. Kangaroo Optimization Algorithm

In each iteration of the algorithm, the following steps are carried out: First, each kangaroo updates its position using the appropriate equation corresponding to its gender. Then, if the kangaroo has a new local fitness value greater than the current global fitness value, the global problem fitness is updated. Finally, each node contains a random fight between two male kangaroo's. The male kangaroo's use the following equation to update position.

$$x_{i,j}^{i+1} = x_{i,j}^{t} + c \times x_{i,j}^{t} \times Gaussian\ (0, \sigma^2) + c \times s \times Rand_1 \times \left(x_{f,j}^{t} - x_{i,j}^{t}\right) + c \times (1 - s) \times v_{i,j}^{t} \times Rand_2 \times (x_{mate,j}^{t} - x_{i,j}^{t}) \quad (4)$$

The following equation is used by female kangaroos to update position:

$$x_{i,j}^{i+1} = x_{i,j}^{t} \times (1 + Gaussian\ (0, \sigma^2) + v_{i,j}^{t} \times Rand_3 \times (x_{mate,j}^{t} - x_{i,j}^{t}) \quad (5)$$

where c indicates kangaroo lost a fight in previous iteration, s indicates single kangaroo, $x_{i,j}^{t}$ stands position at iteration t, $v_{i,j}^{t}$ stands velocity at iteration t, and$x_{male,j}^{t}$ stands position of male kangaroo. With a mean of 0 and a standard deviation of equal to: $Gaussian\ (0, \sigma^2)$ is a Gaussian distribution.

$$\sigma^2 = \exp\ (\frac{Fitness(k) - Fitness(K_{best})}{Fitness(k) + \epsilon} \quad (6)$$

Fitness of kangaroo k at iteration t is denoted by $Fitness(k)$, Fitness value of the kangaroo k's local best is denoted by $Fitness(K_{best})$, and ` is a constant that prevents division by 0 in Figure 4.

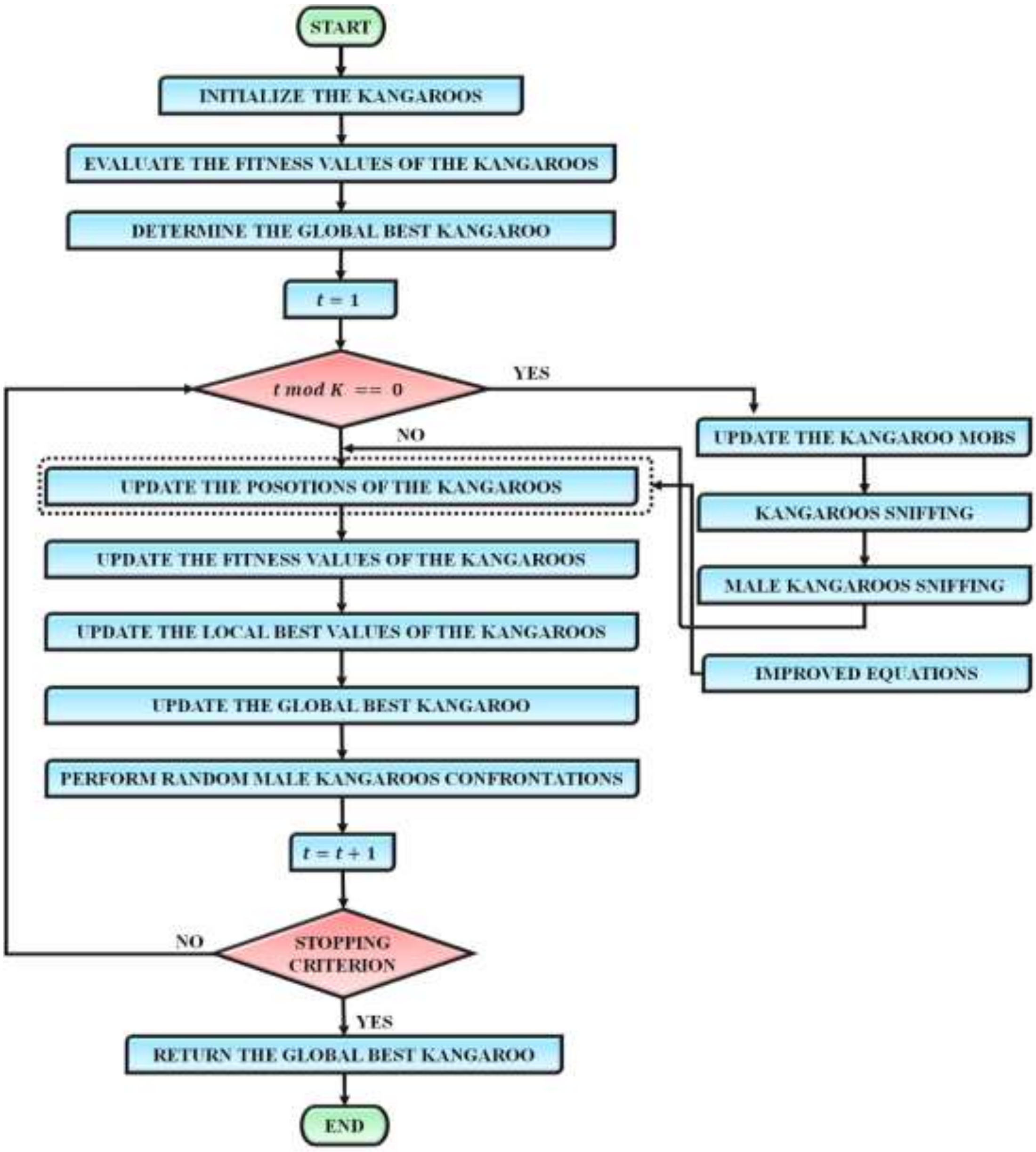

Figure 4. Flowchart for KOA

The below three procedures that form the foundation of the Kangaroo Optimization method are then explained:

Sniffing by kangaroos: Every member of the node updates its local optimal value to the highest local optimum value that any kangaroo in the node has attained so far.

Mutual male sniffing: Mutual male sniffing refers to reciprocal sniffing where the male kangaroos from a stronger node increase their amount of sniffing in relation to the number of male kangaroos from a weaker node.

Male kangaroos engage in combat: if the absolute strength difference between the two males exceeds a certain threshold, the fight is rejected; if not, the strongest kangaroo gains strength with one and the weakest kangaroo loses strength with one; the loser remains motionless in the algorithm's subsequent iteration.

KOA helps to reduce these problems by finding energy-efficient paths, reducing transmission latency, and being adaptable to changing network conditions. It help identify the best route from source to destination.

3. Result and discussion

In result and discussion, the proposed fuzzy logic cluster and KOA routing algorithm for selecting the best CHs and shortest routing paths. The performance are evaluated established on parameters such as energy consumption, throughput, delay, and PDR, and the results are compared to existing system.

Energy consumption

Energy consumption states to total power used via the system when transmitting the data packets. The total energy used by all nodes is represented as:

$$E_c = \sum_{i=1}^{N} E_{i,L} \quad (7)$$

Thus, the total energy used by node i following L rounds of data gathering, and N symbolizes number of nodes.

Throughput

Throughput has been described as the rate at that packets of data have been effectively delivered, measured in bits per second. It is calculated as follows:

$$T_p = \frac{Received\ packet\ size}{stop\ time - start\ time} \quad (8)$$

Delay

The number of time it proceeds for data to get from a sensor node, or source, to its destination is known as the delay.

$$Delay = t_{received} - t_{sent}$$

Here, $t_{received}$ and t_{sent} denotes send and received time.

PDR

The PDR is defined as the ratio of effectively received packets at the point of delivery to all packets delivered from the source:

$$PDR = \frac{packet\ received\ at\ destination}{total\ number\ of\ packet\ send} \times 100 \quad (9)$$

Comparative analysis

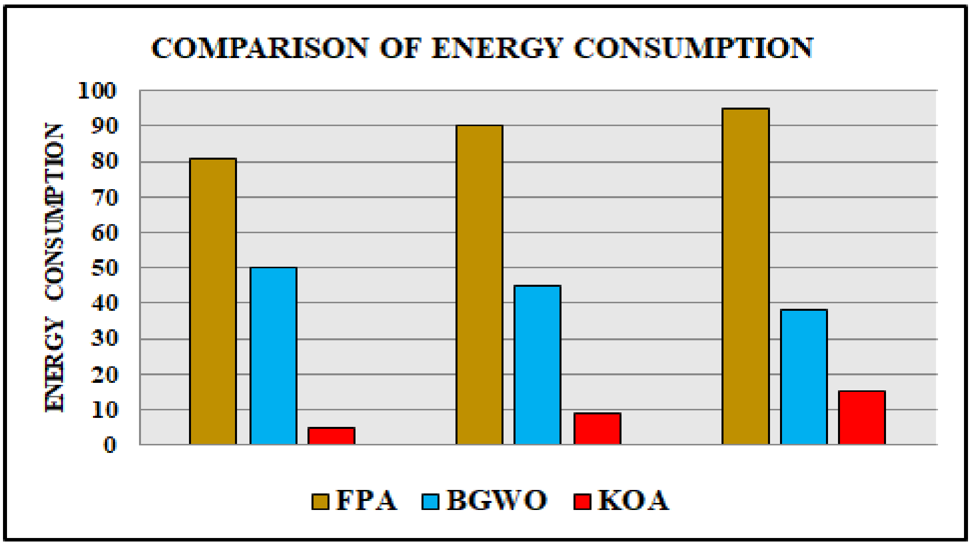

Figure 5. Comparison of energy consumption

Figure 5 compares energy consumption for FPA [17], BGWO [20], and KOA. KOA has the lowest energy consumption across the board and, therefore, is the most energy-efficient. FPA and BGWO generally has the highest consumption.

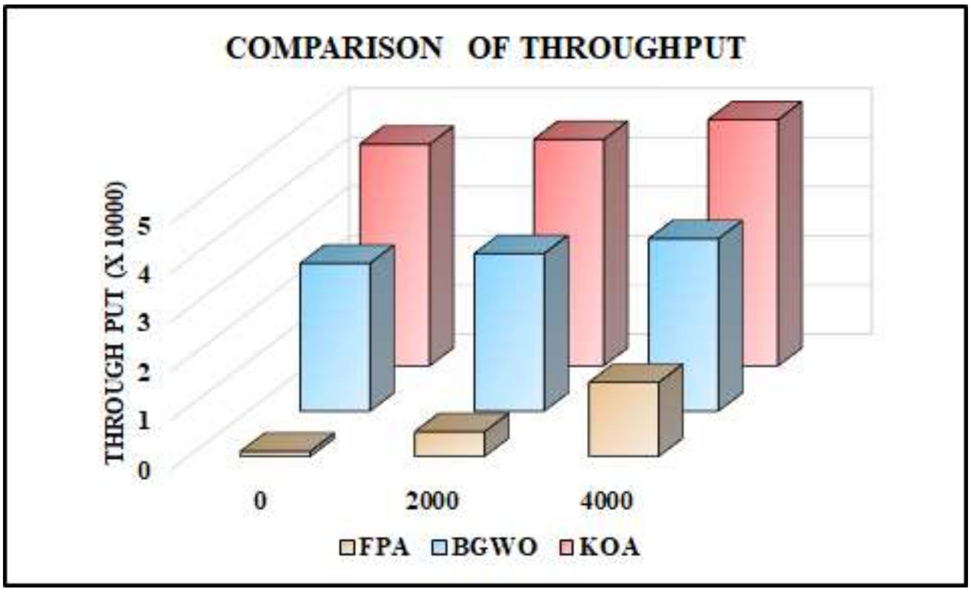

Figure 6. Comparison of throughput

Figure 6 displays comparison of throughput performance for FPA, BGWO and KOA. From the results, KOA has a consistently better throughput across all evaluation points, with FPA and, BGWO has a relatively low throughput. In terms of throughput, the proposed KOA strategy outperforms and better data transfer than other strategies.

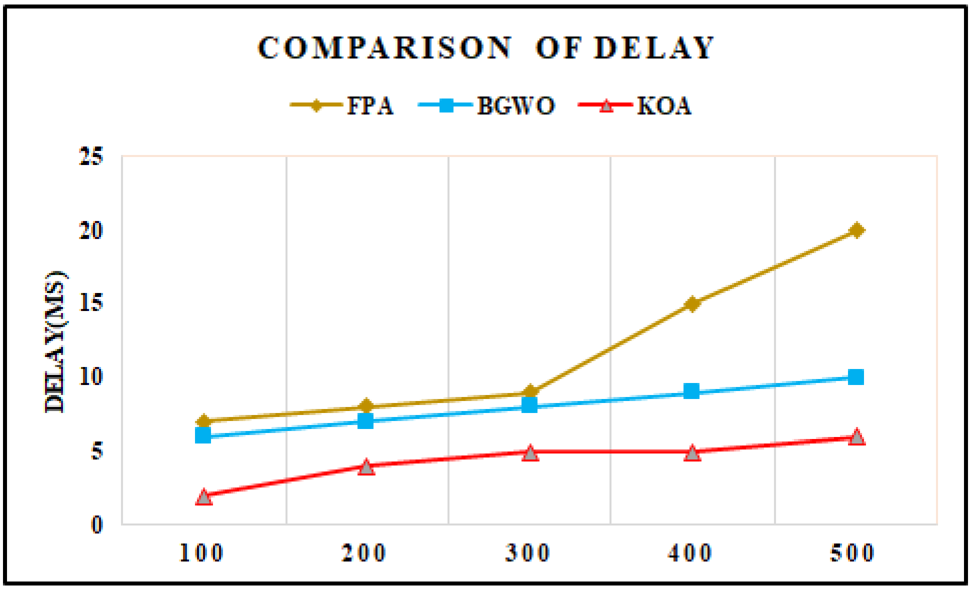

Figure 7 Comparison of delay

Figure 7 shows the delay performance of these same three techniques. KOA has the lowest delay consistently, which means it has the best response or transmission times. BGWO has moderate delay val ues, and FPA has the highest delay which means it provides poorer timeliness performance.

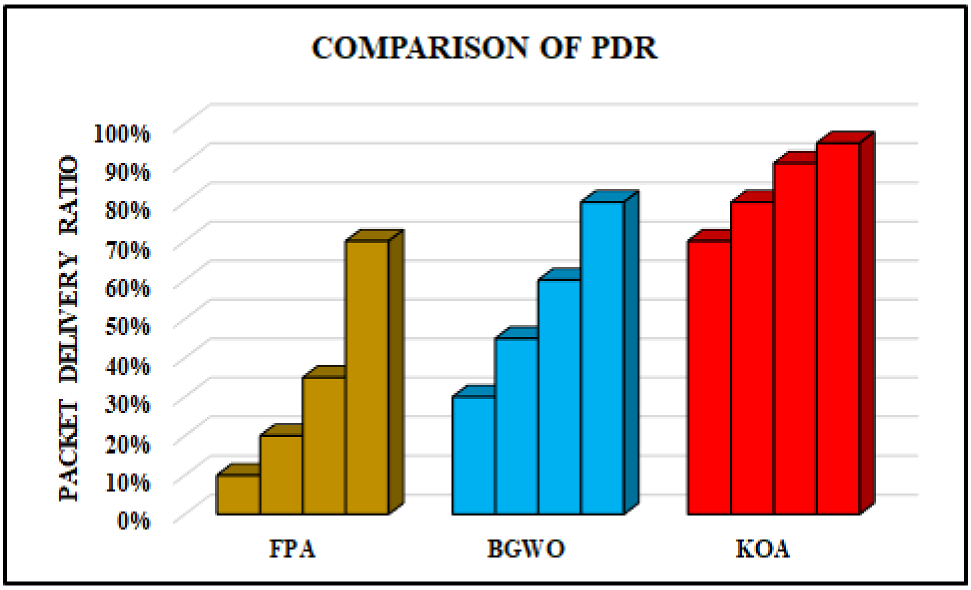

Figure 8 Comparison of PDR

The PDR for the proposed structure is displayed in Figure 8 includes FPA, BGWO and KOA. KOA has the best delivery performance with both a higher and more stable PDR, BGWO and FPA reports the lowest PDR which indicates comparatively weak delivery consistency.

Conclusion

This paper proposes an IoT-based WSNs with CH selection using fuzzy logic and optimal routing using the KOA. The use of fuzzy logic clustering to select and maintain CHs, and that effectively consumes energy factors like residual energy and centrality of nodes in the cluster formation equally. With the aid of KOA efficiently allows for the selection of energy efficient routing paths with minimal communication delay, although improving consistency. Simulation results suggest that the energy efficient protocol outperformed other existing optimization techniques such as FPA and BGWO, in energy consumption, throughput, delay and PDR. Overall, this hybrid approach offers an easily scalable and realistic solution for energy-constrained IoT-WSNs.

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