Hybrid PSO-Bat Algorithm with Fuzzy Logic based Routing Technique for Delay Constrained Lifetime Enhancement in Wireless Sensor Networks

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Abstract

Lifetime maximization of Wireless Sensor Network (WSN) needs energy effective operation and balanced energy distribution among the sensor nodes. Delay restrained WSN applications should implement a routing protocol turn out, which is one of the most crucial tasks in any WSN network. For resolving these issues, the presented hybrid research method concentrates on Distributed Energy Fuzzy Logic routing algorithm (OBDEFL) with delay restraint in WSN's. The proposed method attains the finest trade-off among increasing network lifetime and decreases end-to-end delay in WSNs. The goal of the developed hybrid optimization technique is to resolve energy efficiency in the shortest path trees of the WSN, depends upon Hybrid Particle Swarm Optimization - Bat Algorithm (HPSO-BA) algorithm which increases the overall count of the nodes that are scheduled on a regular timeslot. Hybrid optimization technique with a most popular global optimum search technique of PSO in association with one of the newest search technique called BA and a traditional method of Fuzzy Logic (FL) based routing method for the WSN optimization. The results are measured in terms of packet delivery ratio, drop ration, delay, network lifetime, and Energy Consumption. These metrics are simulated via the use of network simulator 2 (NS2).

Keywords: Distributed shortest path routing, Energy consumption balancing, Fuzzy logic, Lifetime maximization, Minimum-cost routing and Wireless Sensor Networks (WSNs)

1 Introduction

Wireless Sensor Networks (WSN) are extensively utilized in numerous possible applications, for instance, security, environmental monitoring, automation of the plants, surveillance, and control emergency response since a hopeful technique for linking smart object for producing the novel Internet of Things (IoT) [1].

Design criteria include cautious attention for the portion of WSN deployment based on the application requirements and the goals to be attained [2-3]. E.g., the channel characteristics [4-5], network topology [6], resource limits, interference management [7], Bit Error Ratio (BER) and other Quality of Service (QoS) requirements [7] act as a vital character to identify the time span of the network's sufficient operation known as the Network Lifetime (NL) [7-8]. The energy management during data transmission is one of the very interesting and essential tasks in any sensor networks. Energy Consumption Balancing (ECB) is a vital feature for attaining the highest network lifetime, preferably the entire sensor nodes must take energy with the intention that it will reach the limits of their operational duration simultaneously. Several kinds of research presented diverse ECB techniques, depends on numerous network configuration and applications. These techniques were precisely matched up in a broad-spectrum of survey [9].

Routing protocols should focus on increasing the lifetime of the network is to be implemented to develop a suitable trade-off between energy consumption and balancing the energy efficiency. For resolving these issues in WSNs, several researchers have presented. In [10], the authors introduced to shrink the hop count of the route for decreasing the burning of energy for end-to-end transmission and utilized the proportion of recently chosen path hops and the shortest path as metrics.

Azim and Jamalipour [11] presented an enhanced forwarding by fuzzy inference systems (OFFIS) for flat sensor networks. OFFIS protocol supports four descriptors (small hops, shortest path, highest remaining battery power, and link usage) for choosing the best node from candidate nodes in the forwarding paths.

Liao et al. [12] utilized an equivalence clustering method with distributed self-organization for WSNs

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based on their distance and also as the density distribution, considering the best possible configuration of clusters.

Gupta et al. [13] presented a fuzzy based clustering algorithm. There are three descriptors for Fuzzy namely concentration, residual energy, and centrality is used for the time span of the head section of the clusters. In [14], a fuzzy-logic-based clustering method with an addition to the energy prediction (LEACH-ERE) is presented to lengthen the lifetime of WSNs by means of utilizing the fuzzy technique to the workload uniformly.

While creating routing decisions, presented routing protocols for WSNs utilize fixed (crisp) metrics. On the other hand, the association amid an input value in addition to its impact on the performance is frequently nonlinear. Unswervingly utilizing the exact inputs could result in inappropriate routing decision. So as to state this problem, an appropriate nonlinear aligning of the exact input is required. The proposed work concentrates on Optimization based Distributed Energy Fuzzy Logic routing algorithm (OBDEFL) with delay restraint in WSNs. The proposed HPSO-BA algorithm is used in the shortest path tree of the WSN and a fuzzy logic technique is utilized for combining human logic.

2 Literature Review

Haider and Yusuf [15] introduced a method for energy-aware routing in WSNs. This method is soft and adjustable. It is able to handle an extensive kind of energy metrics of diverse sensor implementation platform.

Ran et al. [16] proposed a technique dependent upon Low-Energy Adaptive Clustering Hierarchy (LEACH) utilizing Fuzzy Logic to group together heads selection is presented three variables - node density, energy consumption, and length from the base station.

Liu et al. [17] presented two different algorithms named as Exponential and Sine Cost Function based Route (ESCFR) and Double Cost Function based Router (DCFR).

Taheri et al. [18] presented an Energy-aware distributed dynamic Clustering Protocol (ECPF). It utilizes the methods of (1) non-probabilistic Cluster Head (CH) elections, (2) fuzzy logic, and (3) on demand clustering. Moreover, the selection is accomplished periodically in case of ECPF.

Yuan et al. [19] utilizing the Stable Election Protocol (SEP), WSNs are segregated into clusters. Simulation outcomes illustrated that the presented technique contains important efficiency in regard to even out the usage of power and the network duration in terms of matching up the performance of cluster and A-star (CA) method.

Leabi and Abdalla [20] conferred a novel routing method for increasing the lifetime of WSNs by means of utilizing the Fuzzy System (FS).

Habibi et al. [21] presented a framework to attain the finest results that could be attained by routing technique depends upon the shortest-path method.

Huynh et al. [22] presented a novel analysis of the trade-off among two goals in WSN design: mainly for bring down the energy consumption.

The outcomes of a simulation are reliable with the theoretical analysis. Tian et al. [23] presented a MHCR algorithm, contains multi-path tree and fuzzy inference. Simulation outcomes prove that the presented protocol could balance network load, decrease power usage of the network and proficiently extend the duration of the network.

Al-Kiyumi et al. [24] presented a novel DEFL algorithm, which concurrently states balancing of the energy and energy efficiency. Their simulation outcomes illustrated that the longevity of the network attained by DEFL better results under various conditions.

From the literature, various routing techniques that depend upon a flat multipath routing protocols with simple clustering are implemented. As for the WSNs containing large sensor nodes, uneven nodes distribution density, and real-time changing network topology and the flat multipath routing techniques could create network partition ascertain nodes, which are a portion of the competent path are drained from their battery energy faster.

3 Proposed Methodology

Heuristic routing algorithm based optimization for Distributed Energy Fuzzy Logic routing algorithm (OBDEFL) is presented in this work for enhancing the durability of the network at diverse conditions through merging cost function and fuzzy logic.

Energy efficiency, a Hybrid Particle Swarm Optimization with Bat Algorithm (HPSO-BA) is developed to get optimal solutions.

3.1 Sensor Network Model

The network is comprised of n homogeneous sensors arbitrarily and equally spaced in a target area that is monitored. As a result, the nodes depend upon Reference Signal Received Power (RSRP), distance which is guesstimated.

3.2 Network Topology

Power consumption by node transmission has a major impact due to the selection of specific next hop, therefore reduction of efficiency in routing.

Sensor nodes are running with a duty-cycle for medium access control (MAC) protocol switching their signal off throughout idle time for conserving battery energy [25].

3.3 Traffic Model

Several researches in the present works of WSN routing techniques taken up that the entire network nodes contain uniform rates for generating the data [25]. Traffic patterns could modify from one kind to another kind over a period of time.

3.3.1 Energy Consumption Model

By using the model utilized in [26] for energy dissipation, where in energy needed to transfer a single unit of info from a node 'I' to node 'j' is given in Equation (1).

$$Ene_t(ij) = \beta_1 + \beta_1 ds_{ij}^4 \quad \textbf{(1)}$$

Here $\beta_1 = 50nJ/bit$ is known as the energy utilized to execute the transmitter circuitry, and $\beta_1 = 50pJ/bit/m^4$ is called the energy utilized at the transmitter amplifier and dis_{ij} denotes the distance amid the two nodes. The power needed to execute the receiver circuitry is supposed to be uniform and it is stated as follows: $\beta_3 = 150nJ/bit$.

3.3.2 Lifetime of Sensor Network

The duration of the network will be decreased considerably by this irregular energy dissipation [27].

3.3.3 Formulation of Maximum Lifetime Routing Problem

A WSN is designed as a directed graph G(V, E) here and V is the collection of the entire vertices (nodes) and E is the collection of the entire edges (directed links) of the graph. When j ∈ N_i, a link (i, j) is present, here Ni is known as the collection of neighboring nodes of node i. Every node I contains primary battery energy of Ene_i. G_i is the data generation rate at node i. Consider NetL($\propto$) is the network lifetime and $\propto$ is the equivalent collection of routing decisions. The duration of node i under a specified routing decision $\propto$ is illustrated in Equation (2).

$$Net_{L_i}(\propto) = \frac{Ene_i}{Ene_i^{total}(\propto)} \quad \textbf{(2)}$$

Here $Ene_i^{total}(\propto)$ denotes the overall energy utilized by node 'i' in a unit time and defined as the totality of the complete received energy Ene_i^{re} and the complete transmission energy Ene_i^{tx} in a unit time.

$$Ene_i^{total}(\propto) = Ene_i^{rx}(\propto) + Ene_i^{tx}(\propto) \quad \textbf{(3)}$$

From the Equation (3), $F_k$is the traffic of node k in a unit time comprising the traffic produced by k itself and the traffic got from all its child nodes.

The sets (C_i) and (P_i) gather the child and parent nodes of node i, correspondingly. The network lifetime $Net_L(\propto)$ under routing decisions $\propto$ is known as the highest lifetime over the entire nodes. It is specified in Equation (4) and is given below:

$$Net_L(\propto) = \min_{i \in V} Net_{L_i}(\propto) \quad \textbf{(4)}$$

So, for every node the traffic equation is denoted in Equation (5).

$$\sum_{k \in C_i} F_k a_{ki} + G_i = \sum_{j \in P_i} F_i a_{ij} \quad \textbf{(5)}$$

As a result, the objective function is described and is given in Equation (6).

$$\min_{\propto} \min_{i \in V} Net_{L_i}(\propto) \text{ s.t. } 0 \le aij \le 1,$$

$$i \in V,\ j \in P_i \sum_{k \in C_i} F_k a_{ki} + G_i = \sum_{j \in P_i} F_i a_{ij},$$

$$i \in V,\ \sum_{j \in P_i} a_{ij} = 1 \quad \textbf{(6)}$$

3.3.4 HPSO-BA Optimization

In this research, a novel HPSO-BA optimization is presented to identify $\propto$ that upsurges the lifetime of the network.

Presume $Net_L(\propto)$ is known as the function to be enhanced. In the solution space, every particle is taken as a possible solution for creating routing decision amid sources to destination.

The position vector of nodes (particle i) is denoted as $N_i = (n_{i1}, n_{i2}, ..., n_{iD})$, and its value is computed by a designated fitness function ($Net_{L_i}(\propto)$) that is associated with making routing decision amid the source to destination node to be enhanced. Likewise, $ve_i = (ve_{i1}, ve_{i2}, ..., ve_{iD})$ is known as the velocity vector of particle 'i' that denotes the supplanting of the particle. During evolution, the HPSO-BA brings up its velocity and its position in keeping with the subsequent formulas [28] as described in Equation (7) and Equation (8).

$$ve_i^{t+1} = wve_i^t + r_1 c_1 (p_i^t + n_i^t) + r_2 c_2 (p_g^t - n_i^t) \quad \textbf{(7)}$$

$$n_i^{t+1} = n_i^t + ve_i^t \quad \textbf{(8)}$$

Here 'w' is known as inertia weight that gives a balance amid local exploitation and global exploration; r_1 and r_2 are known as two random numbers resulting uniform distribution in the range [0, 1] at t moment.

c_1 and c_2 are two positive constants known as cognition coefficient; p_i^t is the best prior position for making routing decision of the ith particle at t moment. p_g^t is the finest routing position identified up to now amongst all particles at t moment. Due to its fast convergence rate and easy implementation, HPSO-BA is effectively used to numerous real-world applications. On the other hand, the premature convergence problem is considered as a main issue in PSO. With the aim of resolving this local optima problem, BA is described in equation (9), and is to carried out the present node position n_i of the mutated bats.

$$n_i^{t+1} = n_i^t + Rand \times step \quad \textbf{(9)}$$

Here, 'Rand' is known as a random number and it is sampled from any probability distribution. Step is the step size of bat algorithm. The subsequent approximate or idealized rules are utilized by Echolocation properties of micro bats [29-30]:

1. Each and every bats utilize echolocation to identify distance, and they 'know' the dissimilarity among network lifetime maximization also the background obstacles in certain supernatural manner;

2. Bats fly arbitrarily having velocity ve_i at position xi with a fixed frequency $freq_{min}$, changing wavelength λ and loudness A_0 to seek prey.

They could robotically regulate the wavelength of their emitted pulses and control the rate of pulse emission r ∈ [0, 1], based upon the proximity of their target;

3. Though the loudness could change in a lot of means, take up that the loudness changes from a large (positive) A0 to a minimum constant value A_{min}.

Generally the frequency f in a range [$freq_{min}$, $freq_{max}$] relates to a range of wavelengths [λ_{min}, λ_{max}]. E.g. a frequency range of [20 kHz, 500 kHz] relates to a range of wavelengths from 0.7mm to 17mm.

The novel routing decision position for node x_i^t and velocities ve_i^t at iteration t are specified in Equation (10).

$$freq_i = freq_{\min} + (freq_{\max} - freq_{\min})\beta \quad \textbf{(10)}$$

$$ve_i^t = ve_i^{t-1} + (x_i^t - x_*) freq_i \quad \textbf{(11)}$$

$$x_i^t = x_i^{t-1} + ve_i^t \quad \textbf{(12)}$$

Here β ∈ [0, 1] is known as an arbitrary vector drawn from an equal arrangement. x* is the present global best routing decision with increased network lifetime that is situated subsequently matching up the entire solutions among each one in the n bats. The implementation would utilize $freq_{min}$ = 0 and $freq_{max}$ = 100, based on the domain size of the problem of interest.

Primarily, every bat is arbitrarily allotted a frequency that is evaluated equally from [$freq_{min}$, $freq_{max}$]. For making the calculations to be simple, apply A_0 = 1 and A_{min} = 0is that a bat best route path and provisionally stops emitting any sound and is illustrated in Equation (13).

$$A_i^{t+1} = aA_i^{t+1}, r_i^{t+1} = r_i^0[1 - \exp(-\gamma t)] \quad \textbf{(13)}$$

Here α=0.9 and γ=0.9 are known as constants. The proposed hybrid algorithm that links PSO with BA in random select approach is known as HPSO-BA.

Initially, the parameter m represents the number of added particles in all the iterations.

Next, m particles are arbitrarily selected from the population.

Lastly, the chosen m particles bring up-to-date its node positions by equation (9), and the others are updated by equation (8).

Algorithm 1. HPSO-BA for route or path selection

```
t=1
Initialize M, VE
Find fitness value from equation (6)
Update p_g^t, p_i^t
m= 5// newly added bats
While stop criterion is not satisfied do
t=t+1
Update VE by equation (7)
Select added bats randomly
For every particle in the swarm do
If the particle is selected to add then
      Add M with equation (9)
Else
Update M with equation (8)
End if
End for
Evaluate swarm
Update p_g^t, p_i^t
End while
```

Fuzzy System Implementation

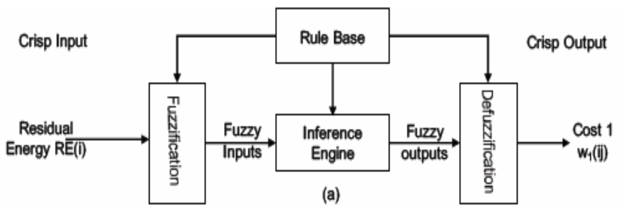
Identifying Cost 1 (w_1(ij)) and Cost 2 (w_2(ij)) of link ij is the main goal of the fuzzy mapping systems. Figure 1 illustrates the design of fuzzy systems.

The energy level associated input is handled by Fuzzy System 1 (FS1). It will consider the normalized residual energy or RE(i) of node i.

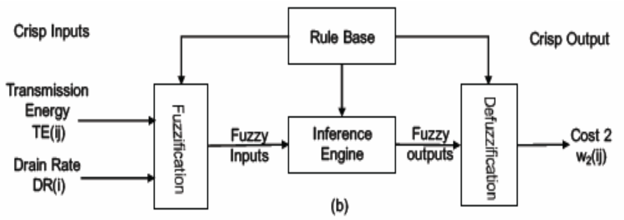
It yields the output variable RP_1(ij), with the intension that w_1(ij) = 1 / RP_1(ij).

The energy consumption rate related inputs are handled by Fuzzy System 2 (FS2), which considers two inputs comprising the energy transmission TE(ij) taken by node i to transfer to node j and the energy drain rate DR(i) of node i. It yields output variable RP_2(ij), with the intension that w_2(ij) = 1/ RP_2(ij).

The subsequent input variables are utilized in identifying the link cost from node i to node j:



(a) FS1



(b) FS2

Figure 1. Fuzzy systems

The residual energy RE(i) for FS1 that is normalized. It denotes node i's energy level. Therefore, its minimum value outcomes in minimum value of relay probability $RP_1(ij)$, outcome of FS1, and as a result greater link cost $w_1(ij)$.

This value is provided added weight utilizing the parameter τ in the over-all link cost calculation w_{ij}. TE(ij) for FS2denotes the energy required to transfer a single unit of data from node i to node j.

Minimum value of the energy transmission yields link$_{ij}$greater probabilities is being chosen for data forwarding that signifies greater probability of relay $RP_2(ij)$, outcome of FS2, and consequently minimum link cost $w_2(ij)$.

While novel crisp inputs reach the fuzzy systems, these are fuzzified to get linguistic values and the resultant rules are provoked.

Any rule, which fires pays to the final fuzzy solution space to calculate the final exact output value from the fuzzy solution space; a de-fuzzification technique is utilized subsequently accumulating the outcomes attained from every rule. The subsequent equation defines the Centroid technique and is illustrated in Equation (14).

$$RP = \frac{\sum_{i=1}^{n} V_i U_A(V_i)}{\sum_{i=1}^{n} U_A(V_i)} \qquad \textbf{(14)}$$

Here, A denotes the solution fuzzy region, RP is the relay probability, $U_A(V_i)$ is called the membership degree for the equivalent output fuzzy set and V_i is known as the centre of the output fuzzy set relating to rule i, n the number of rules triggered in the fuzzy inference engine.

4 Performance Evaluation

In this section, the outcomes are presented by an optimization based Distributed Energy Fuzzy Logic routing algorithm (OBDEFL) algorithm is assessed in regard to energy efficiency, network lifetime, packet drop, energy usage balancing properties and Packet Delivery Ratio for diverse load conditions in the traffic.

4.1 Simulation Setup and Assumptions

As per the previous researches [26-27] and [18], to perform a simulation study with the help of MATLAB software. By keeping an eye on the suppositions and system values utilized in [26] in all experimentations that are:

To utilize [26], routing update period of σ = 5000 bits that is corresponding to contain changes in routing every ten packets of size 500 bits.

Primary network set up is with diverse initial battery capacity Ene_i, when the sink node is presumed to contain unlimited energy resources.

The similar network topology utilized in [26], essentially to guarantee reasonable comparison that works by utilizing the original value of x = 30 for this network. As depicted in Figure 2, the network encompasses 20 nodes that are dispersed in an area of 50 m by 50 m.

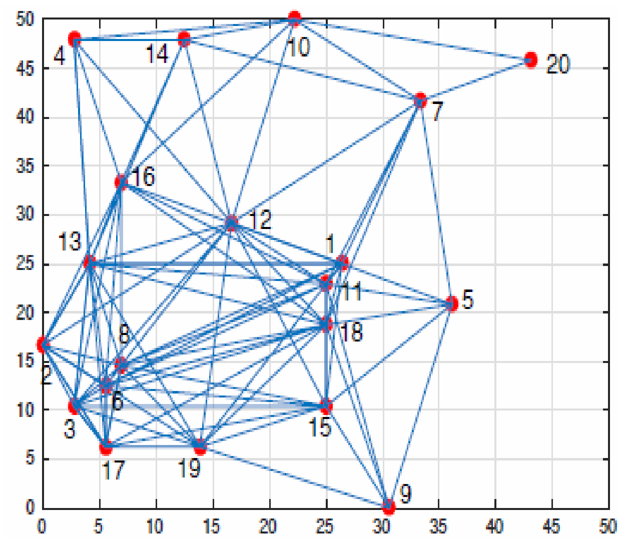


Figure 2. Network formation

There exists one sink node (node 20) and 19 sensing nodes. Every node contains a transference range of 25 m. Nodes 1 and 10 are fortified with primary energy of Ene_i = 80J.

The alternate sensing nodes contain primary energy of Ene_i = 10J. In diverse experimentations, the rate of transmission produced at these two nodes changes, when alternate nodes produce an average of one packet/sec or TR = 1.

The parameters of the simulation are stated in Table 1.

Table 1. Simulation parameters

Criterion	Value
Topological area	50 m x 50 m
Sum of nodes	20
Transmission range	25 meters
Packet size of the data	500 bits
The update period for routing	5000 bits (10 packets)
Power used at the transmitter amplifier	100 pJ/bit/ m^4
Energy dissipated in transmitting circuitry	50 nJ/bit
Energy dissipated in receiving circuitry	150 nJ/bit

Packet Delivery Ratio: The proportion amid the amount of packets obtained with the amount of packets that are sent.

Packet Drop: It denotes the normal number of packets eliminated for the period of the transference.

Energy: It denotes the extent of power consumption in the nodes.

DeLay: It denotes the time interval taken by the nodes to transfer the data packets.

Network lifetime: It is the exact duration at which the initial network node executes beyond energy to forward a packet, and the missing of a node could signify that the network can leave out certain functionality. The total metrics outcomes of the three approaches with four diverse metrics are stated in Table 2.

Table 2. Overall performance comparison results

Rate of Traffic (Packets/sec)	Lifetime of the network(seconds)			The energy dissipated in totality per second(Joules/sec)		
	FLS	DEFL	OBDEFL	FLS	DEFL	OBDEFL
0	1052	1125	1358	0.23	0.21	0.15
10	750	815	958	0.38	0.35	0.18
20	550	625	826	0.56	0.52	0.24
30	390	450	650	0.62	0.58	0.31
40	350	425	620	0.79	0.68	0.42
50	215	356	450	0.93	0.82	0.61
Traffic rate (Packets/sec)	Packet Delivery Ratio (PDR)			Drop ratio		
	FLS	DEFL	OBDEFL	FLS	DEFL	OBDEFL
0	0.78	0.87	0.92	0.22	0.13	0.08
10	0.74	0.82	0.87	0.26	0.18	0.13
20	0.65	0.75	0.82	0.35	0.25	0.18
30	0.62	0.72	0.78	0.38	0.28	0.22
40	0.58	0.68	0.75	0.42	0.32	0.25
50	0.52	0.61	0.72	0.48	0.39	0.28

4.2 Network Lifetime Performance

Figure 3 depicts it is clear that the presented OBDEFL algorithm yields greater network lifetime outcomes of 450 seconds, while other techniques for instance DEFL and FLS algorithms yields only 356 seconds and 215 seconds correspondingly for traffic rate (50 packets/seconds).

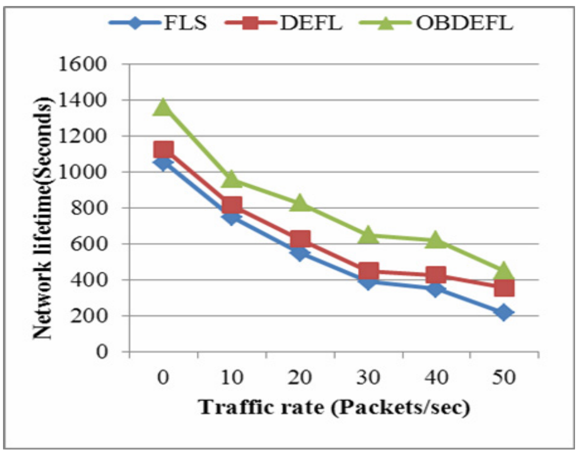


Figure 3. Network lifetime performances of different algorithms

Figure 4 it is obvious that the proposed OBDEFL technique contains minimum energy consumption outcomes of 0.61 (Joules/sec), while other techniques for instance DEFL and FLS algorithms utilizes higher energy of 0.82 (Joules/sec) and 0.93 (Joules/sec) correspondingly for traffic rate (50 packets/seconds).

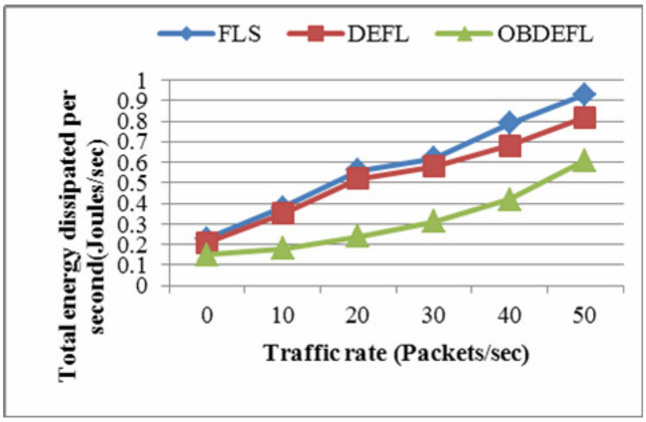


Figure 4. Average energy consumption rate of different algorithms

Figure 5, it is clear that the presented OBDEFL algorithm contains greater packet delivery ratio (PDR)outcomes of 0.72, while other techniques for instance DEFL and FLS algorithms contains lesser PDR outcomes of 0.61 and 0.52 correspondingly for traffic rate (50 packets/seconds).

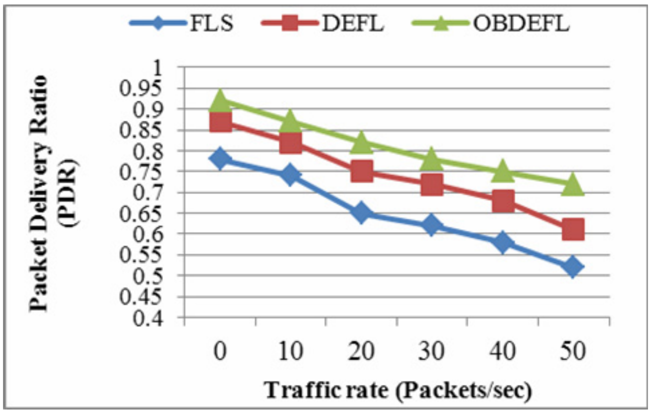


Figure 5. Packet Delivery Ratio (PDR) of different algorithms

Figure 6, it is clear that the proposed OBDEFL algorithm contains smaller drop ratio outcomes of 0.28, while other techniques for instance DEFL and FLS algorithms contains greater drop ratio outcomes of 0.39 and 0.48 correspondingly for traffic rate (50 packets/seconds).

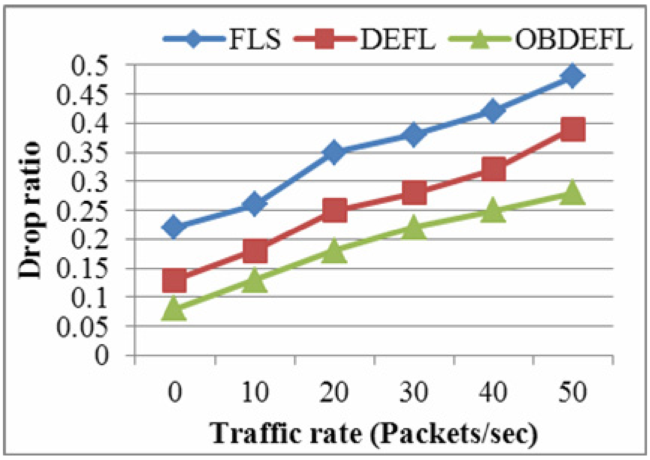


Figure 6. Drop ratio of different algorithms

According to Figure 7, it is clear that the proposed OBDEFL algorithm contains minimum delay of 35 seconds, while other techniques for instance FLS and DEFL contain greater delay of 58 seconds and 42 seconds correspondingly.

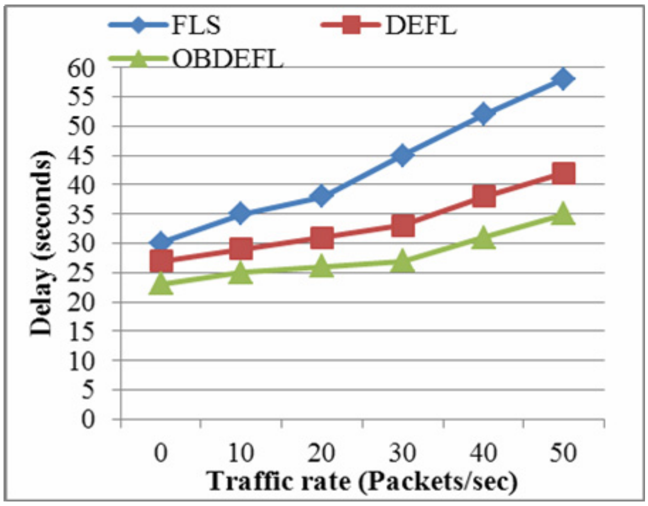


Figure 7. Delay of different algorithms

Table 3. Comparison of delay values (Proposed method with other algorithm outcomes)

Traffic rate (Packets/sec)	Delay (seconds)		
	FLS	DEFL	OBDEFL
0	30	27	23
10	35	29	25
20	38	31	26
30	45	33	27
40	52	38	31
50	58	42	35

From the Table 3 it is clear that the proposed method will yield minimum time delay when compared to FLS and DEFL method for the same amount of traffic rate.

5 Conclusion and Future Work

This proposed research work concentrated to get a global optimum solution for Distributed Energy Fuzzy Logic routing algorithm (OBDEFL) containing delay restraint in WSNs. A Hybrid Particle Swarm Optimization with Bat Algorithm (HPSO-BA) is presented in this research to identify the longevity of a provided network configuration that utilizes as a standard for efficiency. HPSO-BA algorithm that unites PSO with BA operation depends upon a random approach. OBDEFL scheme for implementation of energy-associated cost functions and use fuzzy logic mapping to mix diverse values to attain greater performance under diverse network conditions. In future, the delay restrained WSN applications will implement a routing protocol, which could attain the finest trade-off amid increasing network lifetime and to decrease the end-to-end delay in multi-hop networks.

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