E^{2}MR-HOA: ENERGY EFFICIENT MULTI-HOP ROUTING PROTOCOL FOR WIRELESS SENSOR NETWORKS USING HYBRID OPTIMIZATION ALGORITHM

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Abstract: *Energy consumption is a major issue in wireless sensor networks (WSNs). Many researchers have the focus to reduce energy consumption. The network lifetime of WSNs is affected by energy consumption of sensor nodes. For typical applications such as structure monitoring, border surveillance, embedded in the outer surface of a pipeline, and mounted along the supporting structure of a bridge, the sensor node energy efficiency is an important issue. In this paper, we present an energy efficient multi-hop routing protocol using hybrid optimization algorithm (E^{2}MR-HOA) for WSNs. The proposed routing protocol consist of two algorithms i.e. hybrid optimization algorithm. We present modified chemical reaction optimization (MCRO) algorithm to form clusters and select cluster head (CH) among the cluster members. Then the modified bacterial forging search (MBFS) algorithm used to compute reliable route between sources to destination. The proposed E^{2}MR-HOA protocol is evaluated using NS2 simulations. The simulation result shows that the proposed routing protocol provides significant energy efficiency with network lifetime over the existing routing protocols.*

Keywords: *energy efficient, multi-hop, hybrid optimization algorithm, clusters, cluster heads*

1. Introduction

A lot of work has been carried out in recent past for wide development of applications in WSN and to support these applications many energy efficient routing protocols have developed to deal with limited energy issue of WSN [1], [2]. Sensors may be used in the area monitoring to locate the object, to measure the humidity, to measure the air pollution, to measure the water density etc. WSN is comprised of many tiny sensor nodes [3], [4]. A tiny sensor node is consisted of three subsystems, a communication unit for data transmission, a sensing unit to capture the data from physical environment and a processing unit to process the gathered data [5]. Power source of sensor nodes is battery operated and it is inconvenient to recharge it when SNs are once deployed in unattended atmosphere. A long network lifetime is required from sensor networks by most of the applications, as few months or several years. But how to prolong the network lifetime of the WSN with battery operated nodes is the major issue. Energy conservation is the key concern for WSNs [6].

The main objective of a routing protocol is to efficiently utilize the energy of the nodes. This is because these nodes are not rechargeable and in order to make them useful for a longer period of time, routing protocols have been proposed [7]. Routing protocols improve the lifetime of a network and specifically the stability period of a network. When the sink is static, the probability of coverage holes is greater. After some rounds, there is a possibility that the energy of some part of the network becomes low and results in a coverage hole [8]. Coverage holes are the greatest enemies of a WSN because we cannot monitor the whole network area because some nodes are not functioning.

Furthermore, clustering is an effective method to reduce energy consumption of sensor nodes in large wireless sensor networks [9]. Many recent studies have showed that clustering is an effective routing scheme in increasing the scalability and lifetime. Thus sensor nodes are grouped into clusters in which one of the nodes is designated as cluster head (CH) [10]. A cluster head collects data from other wireless sensor nodes in its cluster, directly or in a multi-hop manner. Typically, data collected from nodes of the same cluster are highly correlated. Data can be fused during the data aggregation process thus reducing the consumption of energy [11]. The fused data will be then transmitted to the base station. This hierarchical network is organized in layers: the lower layer consists of sensor nodes in each cluster for intra-cluster communication, and the upper layer consists of CHs for inter-cluster communication [12]. An effective approach to improve efficiency is to arrange the network into several clusters, with each cluster electing one node as its cluster head [13]. The radio is the most power-consuming module of a sensor node. Another further solution to preserve energy, the nodes should use "sleeping mode", i.e. they turn their radios off but are still able to sense the environment [14]. Once the event of interest is sensed by a node in "sleeping mode", the node turns its radio on.

In this paper, we propose an energy efficient multi-hop routing protocol for wireless sensor networks using hybrid optimization algorithms (E^2MR-HOA). The proposed routing protocol overcome the existing protocol problems and maximizes the network lifetime of sensor networks. We select CH based on lifetime of the node, which improve connectivity between sources to destination.

The remainder of this paper is constructed as follows. Section 2 describes the problem definition and network model of proposed E^2MR-HOA routing protocol and the detailed explanations are discussed in Section 3. Section 4 illustrates the simulation results of proposed routing protocol. Finally, the paper concludes at Section 5.

2. Problem definition and network model

2.1 Problem identification and solution

Haseeb et al. [15] have presented an adaptive energy aware cluster-based routing protocol (AECR) for improving energy conservation and data delivery performance. It generates balance sized clusters based on nodes distribution and avoids random clusters formation. It optimizes both intra-cluster and inter-cluster routing paths for improving data delivery performance while balancing data traffic on constructed forwarding routes and at the end, in order to reduce the excessive energy consumption and improving load distribution, the role of CH is shifted dynamically among nodes by exploit of network conditions. Authors provide balanced clusters without efficient or optimal technique that are not suitable for larger sensor network. In AECR, central point based cluster formation technique not effectively group the nodes in the network. Moreover, clustering and CH selection process depends only on network size. Reliability of routing not achieved by AECR protocol because they didn't consider the node mobility. The energy conservation achieved by conventional method i.e. shorten the transmission distance.

In this paper, an energy efficient multi-hop routing protocol **(E^2MR-HOA)** for WSN is proposed. The proposed routing protocol consists of two optimization algorithm (i.e. called hybrid optimization algorithm). Our major goal is to achieve energy efficiency and to provide better connectivity to increase network/node lifetime. The mobility of node is considered while dealing with choice is made. Firstly, the cluster formation and CH selection performed by modified chemical reaction optimization (MCRO) algorithm and it is inspired from multi-objective CRO algorithm [16]. The proposed MCRO algorithm maintains the balanced nodes in every cluster without adding any extra circuitry. Then the reliable routing between the sources to destination is achieved by another optimization algorithm also called searching algorithm, named as modified bacterial forging search algorithm (MBFS) and it is inspired from adaptive bacterial swarming algorithm (ABSA) [17]. The simulation results depict the energy efficiency, throughput, and lifetime of the network is improved in the proposed protocol. The main contributions of proposed E^2MR-HOA routing protocol as follows:

The MCRO algorithm used to form the cluster and CH. The selected CH node made connection between source and destination. Then the routing path between source and destination will be performed by proposed MBFS algorithm.

The proposed E^2MR-HOA protocol implemented and simulated in NS-2 to compute and compare performance metrics such as Delay, energy consumption, throughput, delivery ratio and network lifetime with existing AECR protocol.

3.2 Network model

The cluster process divides the network area into several groups i.e. clusters and each cluster consists of cluster members and a CH node. The CH having multiple constraints such as energy consumption, end-to-end delay, received signal strength and mobility from each sensor nodes in the network and it is optimized by the proposed MCRO algorithm.

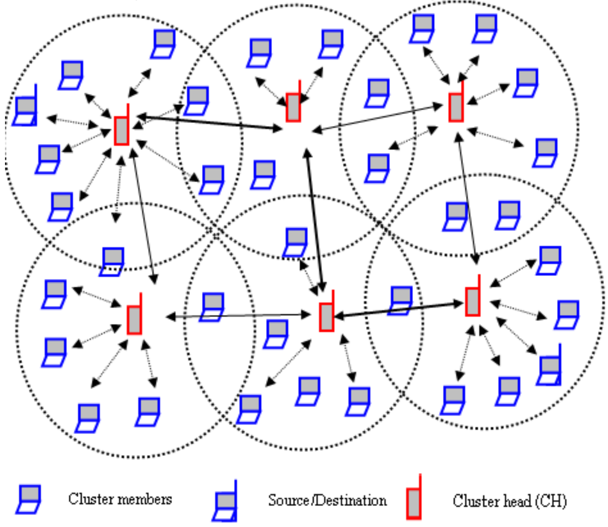


Fig. 1. System model of proposed work

From an optimal result the CH node is selected among multiple members and it is eligible to gather information from members in the cluster and it is forwards via multi-hop routing path. We consider different metrics such as minimum intra-cluster, minimum sink distance, minimum energy and mobility for cluster formation. The network model with example routing scenarios of our proposed work is shown in Fig. 1.

3. Proposed E^{2}MR-HOA protocol

The proposed protocol consists of two processes as clustering and route computation. The clustering is combination of cluster formation and CH selection process, here we use MCRO algorithm and it is described in subsection 3.1. Then compute the routing path using MBFS algorithm and is described in subsection 3.2.

3.1 MCRO algorithm

3.1.1 Clustering using MCRO algorithm

The chemical reaction optimization (CRO) [18] is one of the present variable individuals based swarm data meta-heuristics algorithm. In CRO, a particle, i.e., sub-atomic structure addresses a total strategy. In WSN the sensor nodes are considered as particles as in CRO.

3.1.2 CH selection using MCRO algorithm

The proposed MCRO algorithm is used to select CH among the cluster members by considering multiple constraints such as energy consumption (C_1), end-to-end delay (C_2), received signal strength (C_3), and mobility (C_4). We have normalized the all four objective functions between the range of 0 and 1 for efficient optimization of the function.

Average energy consumption (E_a) defined as follows:

$$E_a = t_a E_{S-CH} + t_s E_{CH-D} \tag{1}$$

$$E_{S-CH} = \frac{\xi_{S_N,CH_1} N_0}{\left|S_N\right|^2} \tag{2}$$

$$E_{CH-D} = \frac{\xi_{CH_1,D_N} N_0}{\left|D_N\right|^2} \tag{3}$$

where E_{S-CH} represents the energy consumption between source to CH node data transmission in an active region during t_a time and E_{CH-D} represents the energy consumption between CH to destination node data transmission in inactive region for a period equal to t_s.

The energy storing metric (E_s) in the time break from t_1 to t_2

$$E_s = \int_{t_1}^{t_2} \left(E_{S-CH,CH-D} - E_{cs}\right) dt \tag{4}$$

where E_{cs} is the power collected and stored power in the same timeline.

The total energy consumption of each sensor node as follows:

$$C_1 = E_{total} = \sum_{k=0}^{t} \frac{E_a(t) + E_s(t)}{E_{cs}(t)} \tag{5}$$

Delay model (C_2) derived from an average intra cluster distance (d_{ic}) is defined as the average of the sum of the distances of all the sensor nodes from their selected CH.

$$d_{ic} = \frac{1}{I_m} \sum_{n=1}^{N} dis\left(S_n, CH_m\right) \tag{6}$$

where I_m is the insertion area between neighboring CH nodes. Average sink distance (d_s) is defined as the ratio of distance between a CH and the destination node.

$$d_s = \frac{1}{I_m} dis\left(CH_m, D\right) \tag{7}$$

In intra cluster and routing phase, all sensor nodes send information to their CH and CH is required to send to the BS. To minimize the average intra-cluster and sink distance of all the CHs by optimal selection approach i.e.

$$C_2 = \sum_{x=1}^{m} \left(d_{ic} + d_s\right) \tag{8}$$

Received signal strength (C_3) based on the metrics such as distance and transmission energy, if the node transmits packet with energy E_{S-CH}, the sensor nodes received signal strength, with the distance of $d_{ic} + d_s$ can be expressed as follows:

$$C_3 = \frac{E_{S-CH}}{4\pi\left(d_{ic} + d_s\right)^2} + \frac{t_1 \cdot t_2}{t} \tag{9}$$

Mobility model (C_4): For moving sensor node fixations, the distance between source to destination changes with time, which make the connectivity issue in remote structure. Consider a situation with source and destination as appeared in Fig. 2. The model which a source focus point is appeared as a straight line. Consider C is the level of the focus point is standard onto the change zone. The distance among source and destination focus diminishes as the source is moving towards the C.

Let $d_1, d_2, \ldots, d_n$ be the link distance that a corresponding moving point of $p_1, p_2, \ldots, p_n$ with the condition of $p_1 < p_2 \cdots < p_n$ and $d_1 < d_2 \cdots < d_n$. In transmission mode, sensor nodes starting to move with one place to other place, which makes relate frustration between sensors to CH.

$$C_4 = \begin{cases} p\left(d_{i+1} < d < d_i\right); \text{ for } i = 1, 2, \ldots, n \\ p\left(0 < d < d_i\right); \quad \text{for } i = n \end{cases} \tag{10}$$

The source focus point moves along the C secured by the CH. Relies on upon the exchanging locales, speed of focus, and their divisions to the reference show are utilized the best CH in the zone. There is just a specific zone where the source focus exhibit is changed next zone, i.e., the point n with $n+1$ as its separation to the reference point.

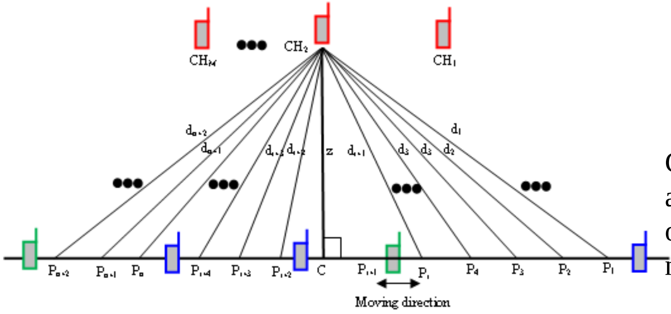


Fig. 2 Mobility model

We have normalized the all the objective functions between the range of 0 and 1 for efficient optimization and the optimal CH selection is as follows:

$$F = q_1 C_1 + q_2 C_2 + q_3 C_3 + q_4 C_4 \tag{11}$$

It is subject to $CH_{node} = Min(F)$ with the multiple constraints are C_1, C_2, C_3, and C_4 the control parameters q_1, q_2, q_3, and q_4 respectively (sum of control parameters equal to 1), and it ensures that those values must not be 0 or 100 % weight.

3.1.3 Cluster formation using MCRO algorithm

Let consider the set of nodes $S = \{s_1, s_2, \cdots s_n\}$ and set of CH nodes $CH = \{ch_1, ch_2, \cdots ch_m\}$. After CH computation the MCRO figuring used to make routing based on life time of the network. The lifetime of the network can be capable by the minimum intra-cluster, minimum sink distance, minimum energy and mobility. We need to minimize intra-cluster distance (d_{is}), sink distance (d_s), energy consumption (C_1), and mobility (C_4) for the optimal formation of clusters. We have systematized these target work values between the level of 0 and 1.

Let $X_{i,j}$ be a Boolean variable as follows:

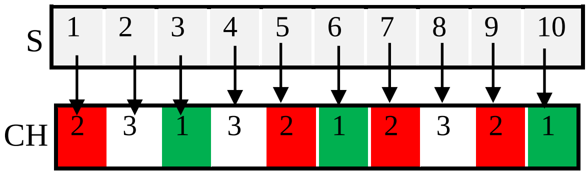
$$X_{i,j} = \begin{cases} 1 & \text{if } S_i \text{ is assgined to } ch_j \\ 0 & \text{Otherwise} \end{cases} \tag{12}$$

where $X_{i,j} = \left(\left(q_1 \cdot C_1\right) + \left(q_1 \cdot C_2\right)\right) \times \left(d_{ic} + d_s\right)$. In cluster formation, structure of molecule represents the assignment of sensor nodes to the CHs.

Let $P_i = \left\lfloor p_{i,1}(t),\ p_{i,2}(t),\ p_{i,3}(t), \cdots, p_{i,d}(t) \right\rfloor$ be the $i\,th$ molecule from population, where each component $p_{i,d}(t)$ maps the sensor nodes to the CH node IDs which are in the communication range of each sensor node $1 \le i \le n, 1 \le d \le D$, where n is the population size and D is the number of characteristics of a molecule.

$$P_i = \left[p_{i,1}(t), p_{i,2}(t), p_{i,3}(t), \cdots, p_{i,d}(t)\right]; \quad 1 \le i \le n, 1 \le d \le D \tag{13}$$

Consider the molecular structure with ten sensor nodes and three CH nodes as shown in Fig. 3 and it can be observed that the index of S denotes the set of sensor nodes and CH indicates that set of CH.



S	1	2	3	4	5	6	7	8	9	10
CH	2	3	1	3	2	1	2	3	2	1

Fig. 3. Sample molecules structure

3.2 Route computation using modified bacterial foraging search algorithm (MBFS)

Working function of adaptive bacterial swarming algorithm (ABSA) [17] based on the movement of the bacteria based on the nutrient content in the network. We modify the fitness computation with multiple constraints of ABSA, which enhance the searching capability of our routing protocol. Our modified algorithm named as modified bacterial foraging search algorithm (MBFS). MBFS algorithm involves the foraging of the bacteria in search of nutrients using four steps such as chemotaxis, swarming, reproduction elimination and dispersal. Here the bacteria move from one fixation to other looking for source to the goal.

Chemotaxis: the bacteria move in small steps in search of nutrition, by swimming or tumbling in a given direction, by sensing and communication with each other. It moves far from the chemo-attractant course, then the genuine living things tumbles, thusly no net relocation in the predefined heading. Since every sensor focus on the structure considered to join microorganisms, we consider focus point N with living animals B.

Let us consider the nutrient gradient of the given path from the node N to node I be the $\delta_{nutrient}(N, I)$.

Swarming: the self-organizing behavior of the bacterium is evaluated.

The signaling of bacteria at the location of I^{th} node towards the N^{th} sensor node can be represented as follows:

$$S(I,N) = \frac{A(I,N)}{e^{D_a d_{in}^2}} - \frac{R(I,N)}{e^{D_r d_{in}^2}} \tag{14}$$

where $A(I,N)$ is the magnitude of attractant released from node I towards node N, $R(I,N)$ is the magnitude of repellent released from node I towards node N, d_{in} denotes the distance from node I to node N, D_a is the diffusion rate of attractant released from node I towards N, and D_r is the diffusion rate of repellent released from node I towards node N. For the principal emphasis, a self-energetic number is considered as scattering rate of intrigue and repellent. After the central cycle, the estimation of scattering rate of intrigue and repellent is settled as follows:

$$D_a = D_r = C_n \times DF \tag{15}$$

In our experiment, the value of diffusion factor (DF) employed was 0.00498 and was observed to provide with a faster convergence range. The centrality of repellent and attractants for each accentuation (after the primary cycle) changes as depicted. Hence, the value of $A(I,N)$ for j^th^ iteration is calculated as follows:

$$A(I,N)_j = \frac{\text{total load in the jth iteration}}{\text{Total noads}} \tag{16}$$

Similarly $R(I,N)$ for j^{th} iteration is calculated as follows:

$$R(I,N) = \frac{\text{Frequency of apperance}}{\text{no of bacteria} \times \text{number of nodes} \times \text{number of step}} \tag{17}$$

For a bacteria at nodes at focus node N, the supplement an inspiration at node I as follows:

$$NU_I = \frac{1}{Load(1)} \tag{18}$$

The supplement part at node, for bacteria, is relating to the store at the sensor node. During tumbling, signaling between two bacteria at I^{th} node towards the N^{th} node is defined as follows:

$$S_t(I,N) = \frac{NV_I}{\delta_{nutrient}(N,I)} + S(I,N) \tag{19}$$

where $S_t(I,N)$ is the signal tumbling between user I to N and assume $\delta_{nutrient}(N,I) = 200$.

Reproduction: we consider the measure of bacteria in a given range as settled. A sound bacterium mimics by part itself into two microorganisms. Inciting of microorganisms is critical in the midst of the attempt of living things, from the good fashioned BS to the sensor node.

Elimination and dispersal: After above-mentioned rounds, it can be watched the microorganisms visits the same branch gathered number of times. Along these lines, the distance between sensor points N and I is a more divisions to a course. The decision of the change sizes is a pivotal issue. If the change sizes are too little, the request will be taken into close-by optima. Clearly, if the structures are too long, the interest will miss the general dumbfounding. After taking this into consideration, equations for long tumble size (LT), short tumble size (ST), and swim size (SW) were defined. Almost every user intervention is needed, due to it being automatically updated during the process. The fitness of MBFS is compute by Matyas function and it represents as,

$$F_{min} = 0.26\left(S_t^2 + S_{t+1}^2\right) - 0.48\, S_t\, S_{t+1} \tag{20}$$

Algorithm 1 Route computation using (MBFS)

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1. Compute the initial fitness values of each bacterium.
2. Let iteration = 0, generation = 0
3. Chemotaxis operator and swarming mechanism
    3.1 Let $f_l$ be represented as the current fitness value.
    3.2 Compute new fitness value $f_n$, when a bacterium runs length unit in the random direction
    3.3 $f_{in}$, the influence value of other bacteria on an bacterium, is computed by $f_n = f_n + f_{in}$
    3.4 Check t < maximum number of steps in the same direction, then t = t+1.
    3.5 Check $f_n$ is superior to $f_l$, then $f_l = f_n$, else t = 0.
    3.6 To walk step length STEP in the same direction, $f_n$ = fitness value of the new position, then go to 3.3.
    3.7 Let iteration=iteration+1, check iteration < N, then go to 3.1, else iteration=0, generation=generation+1, go to 4.
4. Reproduction steps
    4.1 Reproduction operator will be done every 5 generations.
    4.2 Sort descending order by the current fitness values of each bacterium.
    4.3 A healthy bacterium reproduces by splitting itself into two bacteria while the weak bacteria ages and dies with time.
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5. Elimination and dispersal operator
5.1 Elimination-dispersal operator will be done every 20 generations.
5.2 Update range of the current elimination and dispersal.
5.3 Sort descending order by the current fitness values of each bacterium.
5.4 Observed that the bacteria visits same branch multiple number of times.
6. Check the terminal condition and if the terminal condition is satisfied, output optimal solution and algorithm terminates; otherwise, go to 3.

7. Return- Interference aware path between primary BS to SUs.

4. Experimental Results

Our proposed method is simulated using the simulator NS2. We have considered 100-500 nodes for the simulation. These nodes are placed in the region 1000m×1000m with the each node's transmission range 250m. Our proposed method is simulated within 50secs. Table 1 shows the simulation parameters of our proposed scheme. IEEE 802.11 wireless protocol is used. Sensor nodes in the region form number of cluster and cluster head is selected for each cluster using MCRO algorithm. After the cluster formation, data is sent from the source to destination by selecting efficient route using our MBFS algorithm.

Table 1
Simulation parameters

Parameter name	Value
Number of nodes	100 to 500
Wireless protocol	802.15.4
Area	1000×1000 m^2
Simulation time	50 secs
Packet size	512 bytes
Transmit power	0.660W
Receiving power	0.395W
Initial energy	40J
Transmission range	250m
Bit rate	(100-500)kbps

4.1. Performance based on Network size

In this section, performance metrics of our proposed approach is estimated for varying nodes 100 to 500. Figure 4-7 shows that packet delay, delivery ratio, energy consumption and throughput for varying nodes. Our proposed energy efficient multi-hop routing protocol using hybrid optimization algorithm (E^2MR-HOA) is compared with the existing adaptive energy aware cluster-based routing protocol (AECR) [15]. Figure 4 shows the packet delay of our proposed approach. For the set of 100 nodes, our proposed approach has less packet delay. But the packet delay is increased while the number of nodes is increasing. The packet delay of our proposed approach is reduced to 18% than that of existing work. The cluster head in a cluster gathers data from the non-CH members and transmits the received data to the neighbour cluster heads. So the packet delay of our proposed approach is reduced. Figure 5 shows the delivery ratio of our proposed approach. Because of the modified bacterial foraging search (MBFS) algorithm based route selection, delivery ratio of our proposed approach is increased to 42%. Energy consumption of our proposed approach is shown in figure 6. Because of the cluster based transmission, energy consumption of our proposed approach is reduced to 23% than that of AECR algorithm. Figure 7 shows the throughput of our proposed approach. Compared to the AECR algorithm, the throughput of our proposed approach is increased to 58%.

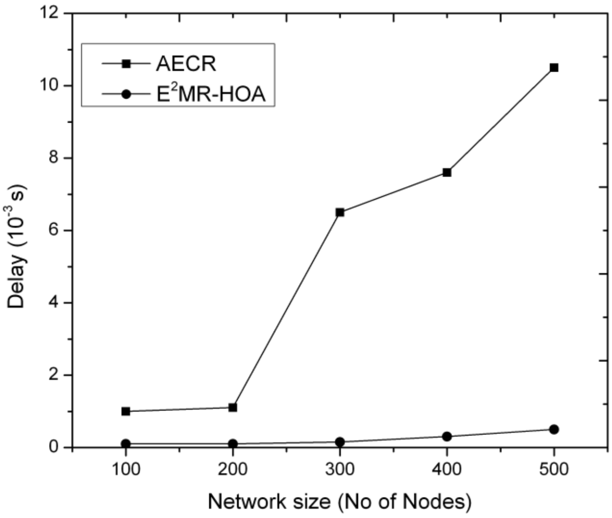

Fig. 4. Network size Vs Delay

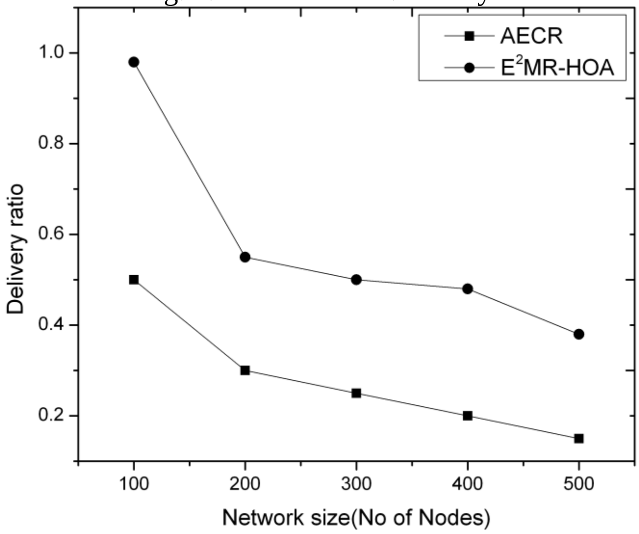

Fig. 5. Network size Vs Delivery Ratio.

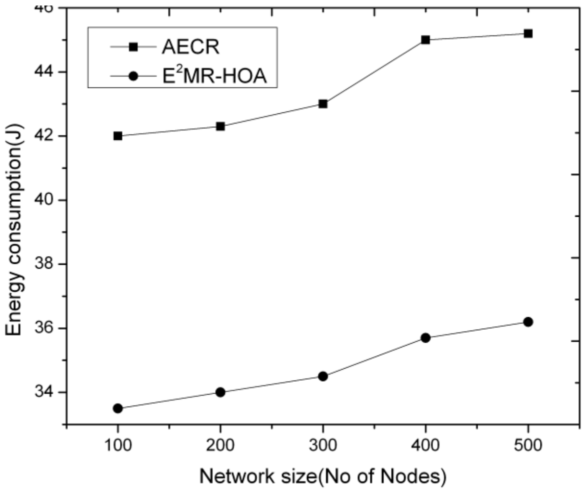

Fig. 6. Network size Vs Energy consumption.

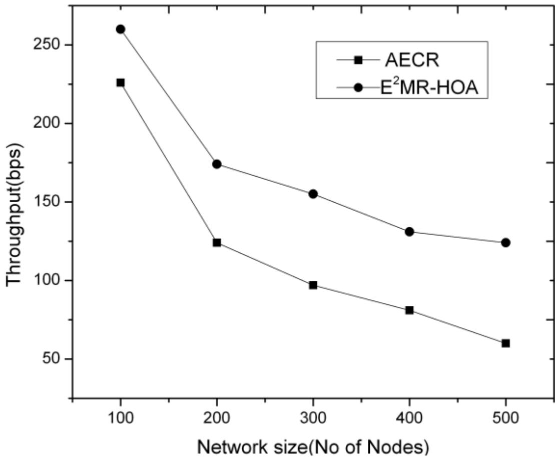

Fig. 7. Network size Vs Throughput

4.2. Performance based on data rates

In this section, performance metrics of our proposed approach is estimated for varying data rates 100, 200, 300, 400 and 500 kbps. Figure 8-11 show that packet delay, delivery ratio, energy consumption and throughput of our proposed approach for varying data rates. Packet delay of our proposed approach is shown in figure 8 and it is reduced to 23% than that of the AECR protocol. Figure 9 shows the delivery ratio of our proposed approach. Compared to the existing work, delivery ratio of our proposed approach is increased to 88%. Figure 10 and 11 show the energy consumption and throughput of our proposed approach respectively. Compared to the existing work, those of our proposed reduced to 23% and increased to 63% respectively. Compared to the existing work, network lifetime of our proposed work is increased to 22%.

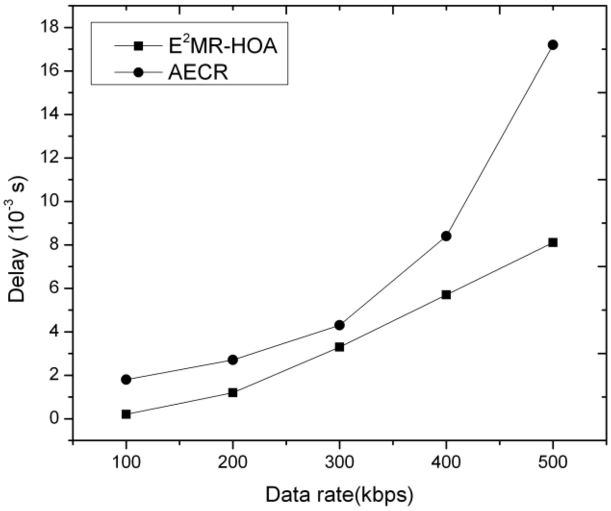

Fig. 8. Data Rate Vs Delay

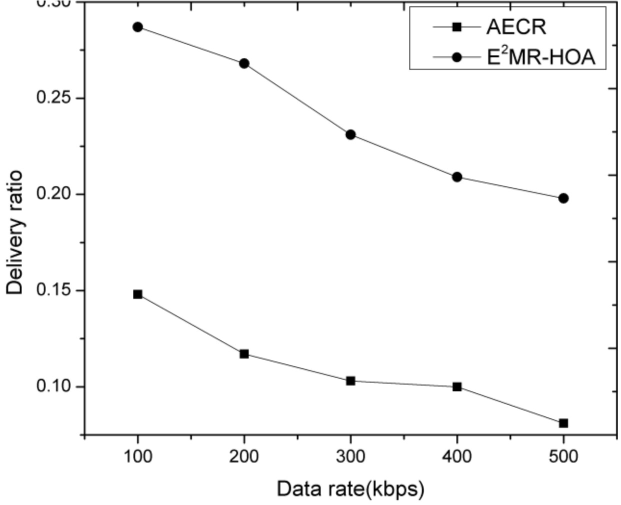

Fig. 9. Data Rate Vs Delivery Ratio

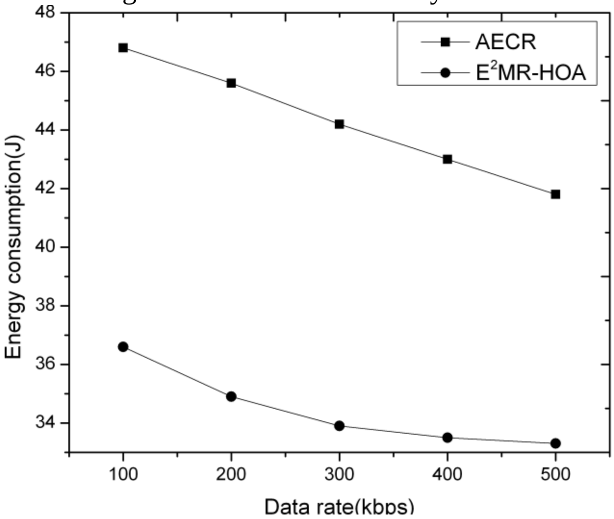

Fig. 10. Data Rate Vs Energy consumption

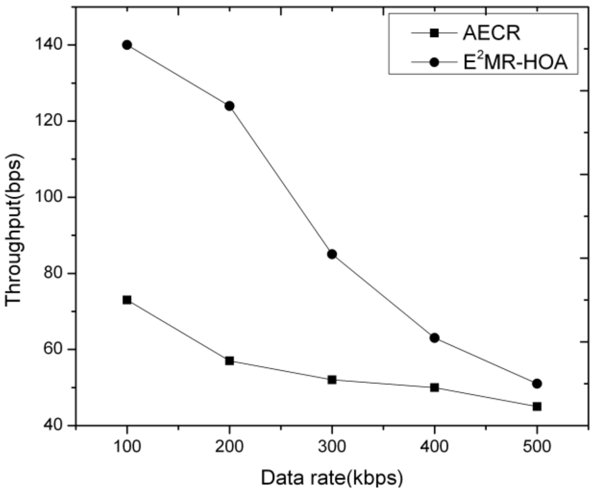

Fig. 11. Data Rate Vs Throughput

5. Conclusion

In this paper we have proposed energy efficient multi-hop routing protocol using hybrid optimization algorithm (E^2MR-HOA) for WSNs and have simulated the proposed work using the network simulator. We have presented two optimization algorithms for our proposed routing protocol. For cluster formation and cluster head selection, we have presented modified chemical reaction optimization (MCRO) algorithm. Then we have established efficient routing between source and destination using our proposed modified bacterial foraging search (MBFS) algorithm. Simulation results showed that energy efficiency and network lifetime of our proposed work have been improved than that of existing work.

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