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Integration of particle swarm optimization with an adaptive K-Nearest Neighbor for energy-efficient clustering in MANET

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ABSTRACT

The objective of the proposed work is to increase the lifetime of mobile ad hoc networks. The energy efficiency issue associated with mobile adhoc network is the critical factor for the success of any MANET system and hence we aim to develop an energy efficient MANET system suitable for any kind of real environment. This paper addresses nodes mobility issue based on a well-known particle swarm optimization (PSO) technique and as well design a cluster algorithm based on adaptive k-nearest neighbor algorithm. The cluster formation is achieved by considering a multi-objective fitness function of PSO and extensive experimentation in the simulated networked environment reveals the performance of the proposed method. In mobile adhoc networks (MANET), optimal energy is one of the critical component and random movement of mobile nodes within a region of interest made it more complex. The provision to have frequent changes in the topology of mobile nodes in addition to keeping the battery life for longer duration is much more complex. The standard metrics such as network lifetime, average number of clusters formed, energy usage and packet transfer ratio are estimated to exhibit the performance of the proposed method. A comparative analysis is carried out with the recently proposed variant of particle swarm optimization based methods to reveal the accuracy and energy efficiency nature of the proposed method. The novelty of the proposed approach include the exploration of optimization algorithm integrating with clustering strategy to increase the energy efficiency of the MANET thereby increasing the lifetime of the network. The proposed approach exhibit better accuracy and possess energy efficient even under scaled environment.

Keywords: *Particle Swarm Optimization, K-Means Clustering, And Mobile Adhoc Networks.*

1. INTRODUCTION

Mobile Ad hoc network (MANET) is a self-configuring infrastructure-less network where mobile devices are connected wirelessly. The devices in the MANET are free to move around independently in multiple directions and hence links are changed frequently which has effect on the topology of the system. As we all know that the device itself acts as a router and must route the traffic on its own. The problem is to maintain the routing information with respect to itself as well as to keep alive in the network for its proper operation. It is required to have the device secured to avoid data hacking by the other systems. A mobile ad hoc network [1] is a self-governing system where numerous hosts are linked together using multi-hop wireless links as shown in Figure 1. This linked-networked system does not have a permanent backbone and the devices are linked on the fly which depends on many factors. The essence of such network can be found in many applications such as search and rescue operations, calamity recovery, defense services, and communication among vehicles and roadside equipment as vehicular ad hoc networks (see Figure 2). There is no principal authority to monitor the network and it is self-configuring in nature. The number of nodes in a linked network would be frequently changing. In order to address the variation among the number of nodes in a network of mobile devices, clustering strategy is emerged as one of the powerful techniques. The nodes are grouped virtually with a central node called cluster head (CH) in each cluster which generally called as coordinator in the cluster group.

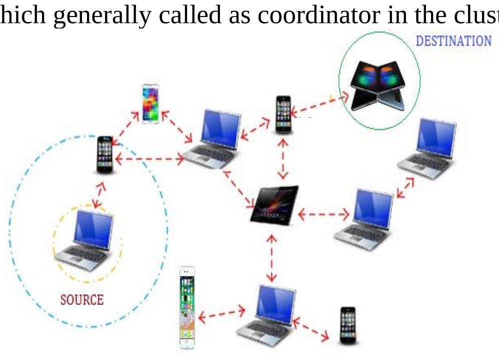

Fig. 1: A mobile ad hoc network.

Fig. 2: MANET applications.

The communication from source to destination is established via cluster heads and hence conserve the energy of other nodes. The reduction in the routing table is achieved due to reduction in the number of nodes participating for the communication establishment. It is the cluster head from each cluster that is responsible for establishing communication between clusters and hence drastic reduction in the energy is saved (see Figure 3). However, the cluster heads need to bear the work load of within-cluster and between-cluster transmission. This process results in energy reduction and hence has the effect on the network traffic as well as routing. Many research works and solutions are being developed out to select the suitable cluster head and hence to resolve the problem of cluster energy depletion. Hence, designing an energy efficient and accurate clustering algorithm which consumes lesser energy is the desired objective in many research works and the proposed work is one such attempt exploring the PSO and adaptive k-nearest neighbor and thereby increasing the lifetime of MANET. In this work, we design a bio-inspired model based cluster head selection and cluster formation algorithms. The cluster head selection approach addresses the selection of the qualified nodes to act as cluster heads from the given set of nodes which hold their connectivity with other nodes for lengthier duration of time.

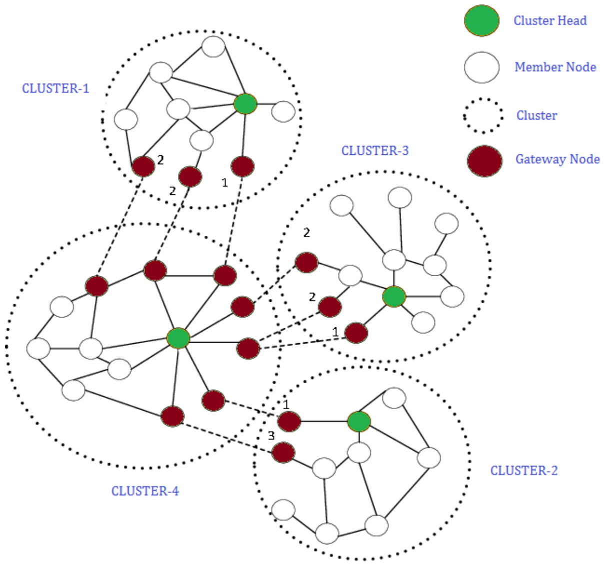

Fig. 3: An illustration of clusters in MANET

In order to develop an algorithm, we have considered several parameters such as the connectivity degree, the needed energy for communicate with neighbors, and the depleted energy level. The direction of the nodes mobility is one of the significant parameter apart from the above parameters. In order to form the cluster, PSO variant is explored which is found to be one of the best stochastic optimization technique. The proposed method uses several agents known as particles which constitute a swarm, travel in search space to obtain the top solution.

Each particle is a probable solution of a problem that tune its movement as per its own movement experience and the movement experience of other particles. Based on the fitness function derived, a node gets attached to a cluster head from the group of cluster heads within its transmission range that has the supreme fitness value. The contributions of the proposed PSO coupled with adaptive k-nearest neighbor approach are presented below:

- The stability of the clusters is preserved which keeps an eye on nodes' mobility along with the direction of movement
- Derivation of fitness function of particles based upon strength of cluster-heads and the average distance of cluster members with their respective cluster heads which increases the lifetime of both cluster heads and cluster members;
- PSO based clustering which effectively balanced loads on cluster heads;
- Inclusion of adaptive k-nearest neighbor method while selecting the cluster heads within the cluster
- Experimental results which exhibit the performance of the proposed algorithm over other existing algorithms in terms of several metrics.

The domain of MANET is growing extensively due to its wide-spread applications and there are ample amount of research works are being carried out which address clustering and routing protocols. In [2], the authors proposed a classification algorithm in the context of MANETs which minimizes the energy utilization of nodes in the clustered network. The weight based clustering algorithm is proposed in [3]. A distributed weighted clustering algorithm for MANET which confines configuration and re-configuration of clusters and restrictions on cluster heads in terms of power requirement is proposed in [4]. In [5], a novel weighted clustering algorithm is developed known as Enhancement on Weighted Clustering Algorithm (EWCA). The parameters chosen for cluster head include transmission power, transmission range, mobility, and battery energy. The load balancing and clusters' stability in MANET is preserved in this approach.

On the other hand, we have seen that there is increased exploration of evolutionary and bio-inspired models in different research areas including optimized network partitioning and route determination in wireless networks. There exists deterministic and stochastic algorithms in recent years for such networks. These algorithms are designed exploring the gradient method and hence is found to be computing intensive. The stochastic methods search in multiple directions which are inspired by biological creatures. A review of diverse class of bio-inspired population based meta-heuristic methods for optimization problems in ad hoc networks are discussed in [6]. A breadth-first-search based clustering method is proposed to select the minimally loaded cluster heads in [7]. An adaptive cluster formation in MANET using PSO method is given in [8]. The authors explored many parameters for choosing the cluster head to have stable clusters. However, the mobility of nodes is not handled effectively. In addition, PSO is used to select efficient cluster heads without considering optimization in the clustering process. In [9], an energy efficient routing protocol for MANET is designed based on the particle swarm optimization approach. In [10], the authors have developed clustering technique in MANET using comprehensive learning particle swarm optimization (CLPSO). The stability of the nodes is not guaranteed here due to cluster head selection process. In [11], the authors developed mobility aware energy efficient clustering for MANET based on the PSO method known as ME-PSO. The direction of mobility of nodes while selecting a cluster head and its energy are considered in this work. In our work, we have considered the mobility of nodes direction along with the additional selection parameters which include the connectivity degree, the needed energy for establishing communication with neighbors, and the energy level depleted. In addition, we have also considered a node distance from the cluster group centre, node speed and node density for cluster head formation process. An adaptive k-nearest neighbor strategy [12] is integrated with PSO method and hence to select the suitable cluster head. This certainly increases the network lifetime as well as balancing loads on cluster heads.
The remaining part of the paper is planned as follows. In Section 2, we present the model that describes energy model, stability model, and an overview of PSO and adaptive k-nearest neighbor algorithm proposed in this work. Section 3 presents the experimental results that exhibit the efficiency of the proposed approach. Finally, in Section 4, conclusions are presented.

2. PROPOSED METHODOLOGY: A PSO–ADAPTIVE KNN-BASED CLUSTER HEAD SELECTION METHOD

The following assumptions are made in the proposed methodology:

- The mobile nodes are deployed randomly within a fixed region and are allowed to travel randomly in any direction.
- The mobile nodes are assigned with unique IDs.
- The mobile nodes are given awareness about their neighbors in order to broadcast their IDs.

It shall be noted here that the communication/data transmission among the nodes is possible when the mobile nodes are within the communication range of each other. The following terminologies are used for formulating the proposed methodology:

- Let M = {m1, m2, m3, … mn} be the number of mobile nodes.
- Let X = {C1, C2, ..., Cp} be the set of cluster heads.
- Let the transmission range of any cluster be Tr(C).

2.1 Energy Model

The energy model characterizes mobile node attribute in a wireless network. "The energy consumption model used in our proposed algorithm is the basic energy model determined by the Class Energy Model in NS-2[13] used to assess node's energy during simulation. The different attributes used are *initialEnergy, rxPower, txPower, sleepPower,* and *idlePower* representing the energy of a node in the beginning, energy consumed in receiving one packet, energy consumed in transmitting one packet, energy consumed in sleep state, and energy consumed in idle state, respectively".

2.2 Stability Model

For selecting the eligible nodes to act as cluster heads from an ordinary set of nodes, combined weights of different parameters are used. Mobility leads to more CH reelection as well as link updating which results in poor cluster stability. Thus, for making stable clusters, it is essential to consider the mobility of the nodes. The transmission range of a node forms a circle with radius consisting of some nodes. Accordingly, we can divide the transmission zone as trusted zone or risked zone. The inner circle with radius forms the trusted zone and the zone forms the risked zone. The coefficients are suitably selected based on the mobility of nodes in the network. In order to decide how well suited a node is to behave as a cluster head, we consider relative mobility and distances with neighbors and the number of neighbors in its direct communication range. We compute the relative mobility using received signal strength between two successive "GOOD MORNING" packets which is inversely proportional to the distance among the sender and the receiver. The relative mobility at a given node with respect to other node is calculated based on the receiving power of the respective packets.

2.3. Particle Swarm Optimization

Particle swarm optimization (PSO) is a population-based stochastic approach for solving continuous and discrete optimization problems. In particle swarm optimization, simple software agents, called particles, travel in the search space of an optimization problem. The position of a particle represents a candidate solution to the optimization problem at hand. Each particle searches for better positions in the search space by changing its velocity according to rules originally inspired by behavioral models of bird flocking. Particle swarm optimization belongs to the class of swarm intelligence techniques that are used to solve optimization problems.

The PSO algorithm starts by generating random positions for the particles, within an initialization region. Velocities are usually initialized within Θ′ but they can also be initialized to zero or to small random values to prevent particles from leaving the search space during the first iterations. In the main loop, the velocities and positions of the particles are updated until a stopping criterion is met.

Each particle in the swarm is represented by the following uniqueness:
x_i: current position of the i^{th} particle,
v_i: current velocity of the i^{th} particle,
p_i: best previous position of the i^{th} particle,
gbest: global best particle in its neighborhood.

The personal best (pbest) position of particle i is the best position experienced by the particle so far. If f is the objective function, the personal best of a particle, at time step Δt is calculated as:

$$p_i(\Delta t+1) = \begin{cases} p_i(\Delta t) & if\ f\left(x_i(\Delta t+1)\right) \geq f\left(p_i(\Delta t)\right) \\ x_i(\Delta t+1) & if\ f\left(x_i(\Delta t+1)\right) < f\left(p_i(\Delta t)\right) \end{cases} \quad \text{..........................(1)}$$

If gbest denotes the global best particle, it is given as:

$$\text{gbest}(\Delta t) \in \{p_0, p_1, \dots, p_s\} = \min \{ f\left(p_0(\Delta t)\right), f\left(p_1(\Delta t)\right), \dots, f\left(p_s(\Delta t)\right) \quad \text{............................ (2)}$$

Here, s is the size of the entire swarm. The velocity of particle i is updated by:

$$v_{i,j}(\Delta t+1) = wv_{i,j}(\Delta t) + c_1 r_1 \left(p_{i,j}(\Delta t) - x_{i,j}(\Delta t)\right) + c_2 r_2 \left(gbest_j(\Delta t) - x_{i,j}(\Delta t)\right) \quad \text{... (3)}$$

where $v_{i,j}$ represents the jth element in the velocity vector of the ith particle, w is the inertia weight, c_1 and c_2 are the acceleration constants, and r_1, r_2 are random numbers. The position of particle i, x_i is updated as:

$$x_i(\Delta t+1) = x_i(\Delta t) + v_i(\Delta t+1) \quad \text{.. (4)}$$

The PSO updates instantaneous motion of particles by using (3) and (4) and this process is repeated until a desired number of iterations are exceeded. The merit of each particle is determined by a fitness function, which reflects the optimal solution. It shall be noted here that each particle tries to modify its position using the following information and in each iteration updates its velocity and position.

The below pseudocode summarizes the general PSO technique.

The pseudo code of the procedure is as follows

```
For each particle
   Initialize particle
END

Do
   For each particle
      Calculate fitness value
        If the fitness value is better than the best fitness value (pBest) in history
          set current value as the new pBest
   End

    Choose the particle with the best fitness value of all the particles as the gBest
   For each particle
      Calculate particle velocity according equation (a)
      Update particle position according equation (b)
   End

While maximum iterations or minimum error criteria is not attained.
```

The main aim of the proposed method is to increase the lifetime of a MANET network by considering mobility as well as energy of mobile nodes which are two important challenging issues. To achieve this, we have designed clustering method with a PSO technique for cluster formation which is coupled with adaptive k-nearest neighbor method. The network setup is achieved in two stages: cluster head selection and cluster formation. The details of these steps are given in the following subsections.

2.4 Proposed PSO–adaptive KNN-based cluster head selection technique

Cluster Head Election: To decide how much a node is capable of becoming a CH, we use its mobility, distances, connectivity degree, and the depleted energy. The first three parameters are combined to form the stability deviation. In order to increase the lifetime of a cluster head, a node with less stability deviation and which depleted less energy is chosen to act as a cluster head. On the basis of stability deviation and energy depletion, the combined weight is calculated in (5). Here W_1 and W_2 are the weighing factors such that $W_1 + W_2 = 1$, the values of which are selected depending on the network scenario.

$$W(n_i) = W_1 \times \mathrm{STD}(n_i) + W_2 \times \mathrm{ED}(n_i) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

A node which is less deviated from stability and depleted less energy is a good candidate to become a CH. Hence, a node with minimum weight among all its neighbors will declare itself as a CH and broadcast a CH advertisement message to all its neighboring nodes.

PSO Based Cluster Formation: This process of consists of swarm of particles initialization, fitness function evaluation and, the velocity and position of particles are updated based on the range of search dimension. Hence, the position and velocity of the particles are governed by its present velocity, its self-progression factor, and the social interaction factor as shown in (3) and (4).
Particles are initialized with an equal number of nodes in MANET by eliminating the set of elected cluster heads; that is, P_i is a set for $i = 1, 2, \ldots, K$, where K is the total number of non-cluster head nodes; that is, $K = N - \Psi$. A particle P_i of generation G is initialized with a randomly generated number in the range of 0 and 1; that is, $0 < \mathrm{rand}(0, 1) \leq 1$ and are independent for different components of particle P_i.

Among the n number of nodes in a cluster, a single subset of samples is retained as the cluster head for testing and the remaining (n-1) subsets of samples are used as training data. This process then repeated n times, with each of the n subset of samples used exactly once as the validation data. Each time value of K for KNN classifier is varied for all the nodes in a cluster. For each K, K numbers of single estimations (SE) are calculated as follows:

$$SE(k) = \frac{1}{2}\sum_{k=1}^{n}\left(\frac{1}{k}\sum_{m=1}^{k} Tr_m + \sum_{m=1}^{k} Ts_m\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Here Tr and Ts are the training accuracy and test accuracy for each run respectively.

From that K number of single estimations, an optimal value is selected. In our case, the optimal value is chosen as: max {SE(K)}. This optimal value of single estimation is named as cluster validation accuracy and the corresponding K value for KNN classifier is selected as cluster head. Selection of cluster head and calculation of cluster validation accuracy are computed for each particle for all the iterations of PSO–adaptive KNN algorithm. We have applied 3-fold cluster validation in this work to reduce the computational time. The performance of each particle is estimated based on fitness function. For our proposed algorithm, the fitness function is based on maximizing the strength of cluster heads and minimizing the within-cluster distance between nodes and their respective cluster heads which is presented below.

Optimizing the Strength of CH: The main objective functions of our proposed PSO based clustering is to enhance the strength of cluster heads. An inadequate distribution of loads on cluster heads results in premature depletion of energy of heavily loaded cluster heads. The death of a cluster head results in link failure which causes an overhead of control messages in either selection of new cluster head or re-grouping. Hence, the clustering effectiveness should also depend upon how nodes are affiliated to a cluster head to form structured clusters. Hence, we have considered the strength of cluster heads as the first optimizing parameter. It depends upon the residual energy of a cluster head and its stability deviation. A cluster head having relatively high residual energy is said to have good strength. Hence, the first objective is to maximize the minimum strength of a cluster head which is computed as follows:

$$S_C = \frac{E_{residual}(C)}{STD_C} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

where S(C) is the strength of a cluster head: **C**, E_{residual}(C) is the remaining battery energy, and STD(C) is the stability deviation of **C** calculated based on the stability deviation. Therefore,

Objective 1: **Maximize S**. That is to: min $\{S(\mathrm{C}) \mid \forall \mathrm{C} \in \mathrm{X}\}$. Hence, the fitness function is directly proportional to the value of S. That is, Fitness $\propto S$.

Optimizing the within-cluster distance between nodes and their respective cluster heads. The second objective of the PSO based clustering is to minimize the within-cluster distance between nodes and the corresponding cluster heads. The weakening of signal strength is one of the features of wireless channel which is directly proportional to the distance between the transmitter and receiver. The generally used model for power attenuation is given by:

$$P_{Rec}(d) = \frac{P_{Trans}}{d_\beta} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Here, $P_{\text{Rec}}(d)$ is the received signal amplitude from a sender at a distance of d from the receiver, P_{Trans} is the strength of the transmitted signal, d is the distance between transmitter and receiver, and β is the path loss factor. As the rate of energy depletion increases such nodes die quickly, resulting in degradation of network lifetime. So, focus should be given to assigning a node to the nearest cluster head from the set of cluster head within its range so as to minimize the energy depletion for intra-cluster transmission. We therefore considered our second objective is to minimize the average distance between nodes and their respective cluster heads. The average distance is computed as follows:

$$AvDist = \frac{\sum_{i=1}^{k} dist(n_i - C_i)}{|k|}, \forall n_i \in T_{range}\ (C_i) \Lambda\ C_i \in X \quad \text{.......................} \ (9)$$

Hhere $|k|$ is the cardinality of all nodes that belong to the transmission range of C_i ($T_{\text{range}}(C_i)$) and X is the set of elected CHs. Therefore,

$$\text{Fitness} \propto \frac{1}{AvDist}$$

This means:

$$\text{Fitness} \propto \frac{S}{AvDist} \quad \text{...} (10)$$

Thus, the objective of the PSO based clustering is to maximize the fitness value given in the above equation. The more the fitness value of a particle is, the more the compact clusters with optimum cluster head s are created with the constraints that a node can be assigned to one and only one cluster head and it should be within the transmission range of the cluster head. This ultimately will increase the lifetime of the CHs and also the lifetime of non-cluster head members and so increases the overall network lifetime. Each particle periodically updates the Pbest and Gbest value after evaluating its fitness function.

Update Velocity and Position of Particles. Particles, after evaluating their fitness function, compute their velocity and position respectively using (3) and (4). The velocity and position are updated in every iteration and the solution move toward the best likely result. The iteration repeats and each time the particle's current fitness value is compared with its personal best value. Due to better fitness, the personal best, Pbest$_i$, is replaced by the current value. Also, the global best, Gbest, is updated upon obtaining the global best fitness. The update in velocity and position continues till the satisfaction of a termination criteria. We made the number of iterations as the termination criteria in the proposed work. After the completion of the clustering algorithm, nodes are assigned to their respective optimized cluster heads and are minimally distant away from their respective cluster head achieving more compact and balanced clusters.

3. EXPERIMENTAL RESULTS

We present in this section, detailed experimental results. The existing clustering algorithms are considered for comparative analysis. The adaptive clustering method with particle swarm optimization (A-PSO)[8], comprehensive clustering based particle swarm optimization (CL-PSO)[10], and mobility aware energy efficient clustering based particle swarm optimization (ME-PSO)[11] algorithms are considered for comparative study. The NS-2 network simulator is used in the experimentation. The experimental set-up is similar to the experimental set-up considered in the algorithms chosen for comparative study. The number nodes are varied from 20 to 100 and are deployed in the region of around 800mx800m. The transmission range considered varies from 10m to 200 m and nodes are initialized with an initial energy of 75000 NJ. The simulation settings are presented in Table-1. The experimental results depict the efficiency of the proposed method with ME-PSO, A-PSO and CLPSO in terms of packet delivery ratio (PDR), average end-to-end delay, energy consumption and network lifetime.

Table 1: Simulation parameters for experimental analysis

Parameter	Value
Number of nodes	20–100
Simulation area	800 m × 800 m
Simulation time	500 sec
Simulation iteration	100
Initial energy	75000 NJ
Packet size	512 bytes
Packet rate	35 packets/s
Transmission range of nodes	10 m–200 m
Routing protocol	AODV
Traffic type	Constant bit rate (CBR)
Movement model	Random-way point
Maximum speed	20 m/s
Radio propagation model	Two-ray ground

The packet delivery ratio is estimated where we have increased the packet rate. The number of packets reached the destination decides the accuracy of the method and in this context, the proposed method achieve better accuracy when compared to A-PSO and CLPSO and is on par with ME-PSO method. The stability model is one of the component responsible for providing the improved accuracy. The path breakage due to movement of cluster head is reduced and hence we have observed the improved packet delivery ratio. The packet delivery ratio estimated for varying packet rate is presented in Fig. 4.

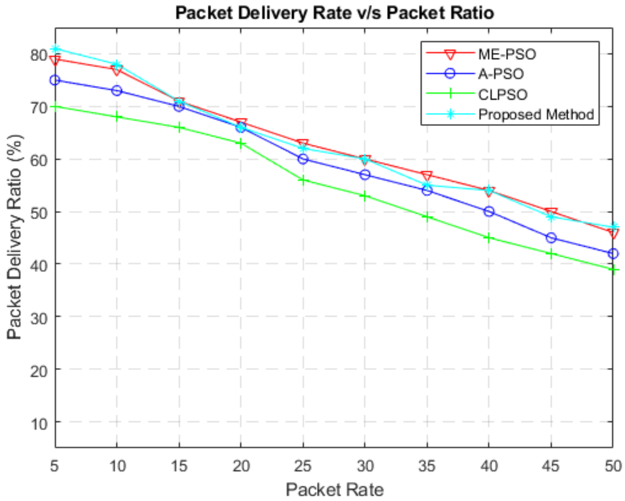

Fig. 4: Packet delivery ratio versus packet rate

We have also studied the average end-to-end delay which reveals about the participation of the number of nodes to communicate from source to destination. The strength of the cluster head make it consider it as one of the potential member for communicating the packets from source to destination. The cluster head energy is considered as one of the parameter while transmitting the data from source to destination and hence able to retain the cluster head for longer duration and thereby enabling assured packet delivery. The computed average end-to-end delay due to varying number of packets is presented in Fig. 5

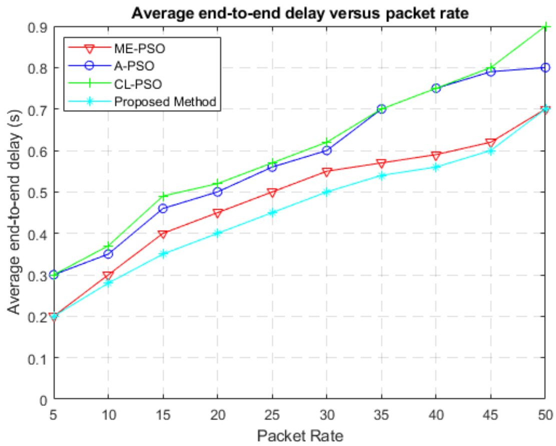

Fig. 5: Average end-to-end delay versus packet rate

The remaining battery energy per node is studied considering the proposed method couple with AODV routing protocol and mobility aware energy efficient based PSO based algorithm coupled with AODV routing protocol. The remaining battery energy per node with varying number of nodes is considered for study and the experimental results are presented in Fig. 6.

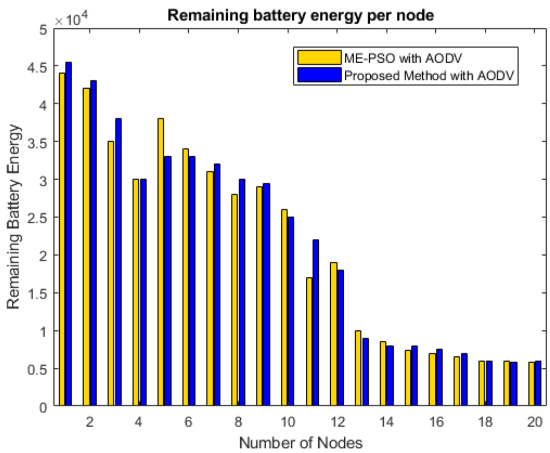

Fig. 6: Remaining battery energy per node

Lastly, we have considered the network lifetime metric. It shall be observed from the Fig. 7 that the proposed method performance is on par with one of the recently proposed ME-PSO method and is found to be better than the A-PSO and CL-PSO method.

Hence, we conclude that the proposed PSO method integrated with adaptive k-nearest neighbor method is useful in mobile adhoc network for communicating the packets without suffering from energy issue and packet loss.

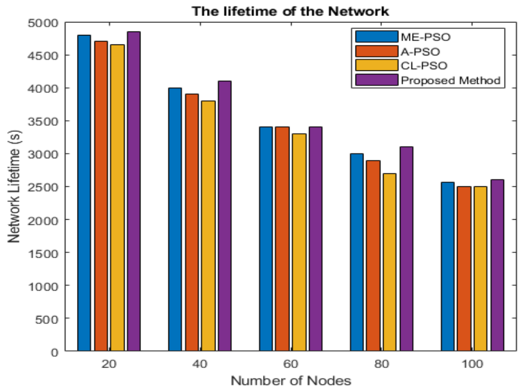

Fig. 7: Network lifetime versus number of nodes

4. CONCLUSIONS

In this paper, we proposed an energy efficient model that addresses nodes mobility issue in MANET based on well-known particle swarm optimization technique and as well designed a cluster algorithm based on adaptive k-nearest neighbor algorithm. The cluster formation is achieved by considering a multi-objective fitness function of PSO coupled with adaptive k-nearest neighbor method and extensive experimentation in the simulated networked environment reveals the performance of the proposed method. The standard metrics such as network lifetime, average number of clusters formed, energy consumption, and packet delivery ratio are estimated to exhibit the performance of the proposed method. A comparative study is provided in order to reveal that the performance of the proposed approach is on-par with the recently proposed PSO based methods.

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