Energy effective routing optimisation using ACO-FDR PSO for improving MANET performance

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Abstract: Autonomous devices that are interconnected in an on demand fashion that communicate in wireless medium with the available energy constitute mobile ad hoc networks (MANETs). Communication in these networks is restricted to lifetime of the nodes that in turn dependent upon the node's battery power. Therefore optimisation is necessary to prolong node lifetime and communication period. This work proposes a hybrid ant colony optimisation (ACO) combined with fitness distance ratio particle swarm optimisation (FDR PSO) to optimise energy. ACO finds the energy efficient path in the network based on higher residual energy and FDR PSO minimises energy consumption of the network, to enhance node lifetime which ensures energy efficient routing. Duty cycle algorithm collaborated with ACO swaps the nodes between active and sleep state depending upon their utilisation. This prevents a node being active all time though it has no communication at that instant of time. The proposed hybrid technique (ACO-FDR PSO) is tested over a 100 node network scenario. The impact of varying number of nodes and their speed on the performance metrics such as throughput, packet delivery ratio, drop and residual energy have been analysed using NS-2 simulator.

Keywords: ant colony optimisation; ACO; duty cycle; FDR PSO; MANET; residual energy.

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1 Introduction

Mobile ad hoc networks (MANETs) are collection of self routing enabled devices that communicate among themselves without any specific network infrastructure. Obviously, these networks are decentralised and rely on neighbours for communication. The topology of the networks is not fixed and is subjected to change over time due to the mobile nature of the devices. The network communication between a source and destination is generally in multi hop for which energy of the devices plays a vital role besides mobility. The process of routing in energy dependant networks needs to meet stability and sustainability throughout the communication period. Simply, the link stability and flawless communication relies indirectly over the energy of the devices. Routing protocols are responsible for ensuring energy efficient path discovery and attempts to reduce energy consumption of the nodes, in the network. Major routing protocols minimise energy consumption by selecting minimum hop distant nodes, in order to improve transmission rates or to minimise delay in transmissions. Recent approaches in energy routing concentrates in selecting specific nodes based on their available residual energy (RE) by which the protocol/technique is trusted to achieve energy efficiency with other limited network performance (Venkateswaran et al., 2009; Li and Haas, 2016).

Researchers proposed many optimisation solutions for achieving energy efficiency in these decentralised networks. Some of them are routing based on minimum energy utilisation and on aiding lifetime maximisation.

Routing protocols intend to uplift and retain network operations for longer time ensuring efficient paths between communicating nodes. Prolonged communication can be achieved by minimising node's energy consumption during its active and inactive states. Following are the existing methods proposed to achieve energy efficiency in ad hoc networks.

Routing protocols based on transmission control (Kamboj and Sharma, 2008) utilises multi hop transmission with minimal broadcast to introduce source node to the other nodes in the network. The nodes in the network adjust their transmitting radio energy such that the power is sufficient to route the destination.

Suresh et al. (2014) proposed efficient power aware routing protocol (EPAR) based on min-max formulation. EPAR minimises the energy consumption of neighbours in the coverage region to extend the lifetime of the operating nodes. EPAR lacks in retaining backup routing paths to overcome link failures.

Varaprasad and Narayanagowda (2013) proposed another variant of DSR called efficient DSR (EDSR). EDSR optimises network by minimising energy consumed at packet level, detects and eliminates selfish nodes and maximises network lifetime by avoiding energy drops. The same authors proposed an efficient power routing protocol that is built over DSR (Shankar et al., 2014) to improve both node and link lifetime.

A battery cost routing protocol based on min-max function is proposed by Qing and Lang. The protocol discards nodes with lesser battery capacity and admits better energised nodes for seamless communication (Zhao and Tong, 2005).

Toh et al. (2001) proposed conditional max-min battery capacity routing (CMMBCR). CMMBCR determines a threshold for the path nodes; a node with energy above threshold is selected for transmission, failing which will be avoided from participating in transmission.

Unlike the previous approaches, Yang et al. (2008) proposed a power aware multipath (PAMP) routing in which the both source and destination is aware of the remaining energy of the active communication path through RREQ messages. With this knowledge, PAMP replaces an energy failure path with the next available path to continue transmission. In PAMP, neighbour path bandwidth decreases and energy consumption increases due to mobility.

Tan et al. (2006) devised a lifetime aware multipath optimised routing (LAMOR) to improve network lifetime in multipath transmissions. LAMOR uses more than one displaced path for aiding multipath transmission. Other than discarding a low energy node, LAMOR moves the node to sleep state preventing early retard in network lifetime.

An energy saving routing aided by ant colony optimisation (ACO) called A-ESR is proposed by Kim et al. (2011). A-ESR collects the traffic and delay information of the path nodes and selects nodes that are less overloaded for packet forwarding. Though A-ESR balances network load, it lacks in retaining appreciable amount of RE that sustains network communication.

Based on ant colony approach, an adaptive routing technique called anthoc max-min-path (MMP) is proposed by Vijayalakshmi et al. (2016). MMP method aids to prolong the active time of the paths between nodes. The forwarding ants update their pheromone value based on the defined energy cost function of the path. MMP also detects link failures in forehand to prepare transmission through alternate optimal paths. This method improves packet delivery ratio, network lifetime and minimises packet retransmissions.

Kumaran and Ramasamy (2016) projected an integrated optimisation technique using ACO and GA. ACO finds all possible paths between source and destination. Among these paths, GA eliminates the weaker paths and selects an optimal path based on fitness value. Penalty functions of RE and bandwidth is considered as fitness function in GA. The integrated approach improves bandwidth utilisation and minimises energy consumption. GA-based optimisations integrated with meta-heuristic approaches levitate overall QoS rather than limited factors.

Kim and Jang (2006) modified the RREQ of AODV routing protocol to store the energy information of the intermediate nodes. The intermediate nodes on receiving the

RREQ packet update their energy value to the RREQ field. The destination computes the mean path energy and transmits it to the source via RREP. Source selects an energy efficient path based on current and opportunistic RREP from the destination. This method aims at conserving energy and prolonging network lifetime. Protocol packet modification is limited to the type of routing performed.

Robinson and Rajaram (2015) anticipated a PSO-based multipath aiding energy aware routing called EMPSO. EMPSO considers transmission cost, energy and traffic ratio of each intermediate node. CRTNN computes weight based on the above factors and the node with higher weight is selected as best solution by PSO.

A random network coding-based duty cycle algorithm was developed by Rout and Ghosh (2013) to minimise the energy consumption of nodes by exchanging nodes between two states namely: active and sleep states. This method is based on network coding that improves the network lifetime and packet delivery ratio.

A location-based ACO called ALEEP is given by Vallikannu et al. (2015), that selects neighbours based on position and RE. ACO integrated ALEEP locates nodes through RSSI and selects a neighbour in shortest distance and higher RE for routing and packet transmission. This method is proposed for MANET nodes that tend to improve throughput and minimises packet drop.

From the above survey, attempts are made to provide the following contributions in this paper:

A hybrid optimisation technique of ACO with fitness distance ratio particle swarm optimisation (FDR PSO) is developed to optimise the network performance by adopting energy efficient path. Besides, duty cycle algorithm is implemented to minimise earlier energy drain that prolongs the communication period of the nodes by extending their time-to-live (TTL) period. The two-fold approach is compared with traditional AODV and ACO-based ALEEP method to prove the effectiveness of the proposed approach.

2 Problem formulation

Energy efficient routing and optimisation in MANETs requires a trade-off approach, compromising either energy efficiency or other network metrics like distance, delay, data rate, etc. Therefore, optimisation techniques must be designed to concentrate in minimising trade-offs to support the growing network population. A hybrid technique is proposed that concentrates in optimising energy and its related network parameters with minimum compensation. The hybrid technique integrates ACO and FDR PSO to enhance energy efficiency of the network. ACO concentrates on enhancing the life time of nodes by adopting duty cycle algorithm and FDR PSO optimises energy consumption of the nodes.

The energy consumption (E_c) of the node (Maleki et al., 2003; Saraswat and Bhattacharya, 2013) is given by equation (1)

$$E_c = E_t + E_r \tag{1}$$

where E_t and E_r are the energy used by the nodes for transmission and reception.

The energy utilised for transmission and reception are computed using equations (2) and (3)

$$E_t = d_t \times e_{ut} \times t_t \tag{2}$$

where d_t is the rate of data transmission, e_{ut} is the energy utilised for the transmission and t_t is the transmission time.

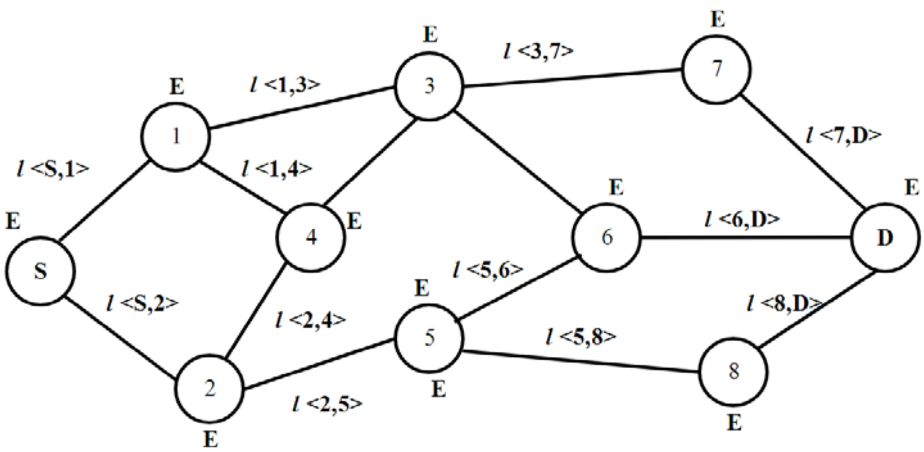
$$E_r = d_r \times e_{ur} \times t_r \tag{3}$$

where d_r is the data reception rate, e_{ur} is the energy utilised for the reception and t_r is the time at which data is received.

2.1 Network model

A MANET environment is considered with 'n' nodes representing {N}. Each node is connected with its neighbour using a link *l*, separated by a distance 'd'. If node 'i' is the neighbour of 'j', then the distance between the nodes d(i, j) must be less than or equal to the transmission range of the node 'i', i.e., d(i, j) ≤ TR(i). Nodes possess variable velocity pursuing random way point (RWP) movement pattern. The model of the MANET is illustrated in Figure 1.

Figure 1 Network model



2.2 Energy concentrated ACO-FDR PSO approach

The proposed hybrid approach of ACO-FDR PSO works in two diversified approaches.

2.3 ACO

ACO algorithm is aimed to optimise RE. The node having higher RE is chosen for transmission based on duty cycle algorithm.

Initially, ACO selects energy efficient path for data transmission between source and destination by visiting intermediate nodes between them. After the completion of ant traversal, with all hops visited, the pheromone values are updated. The pursuing sets of ants are attracted towards the higher pheromone concentrated links updated by the ancestors. After 'k' transmissions, ACO updates the RE of each of the visited nodes. The successive ant set generated is attracted towards the higher RE node rather than random dispersion and the transmission path is selected through them. The current active nodes will be moved to sleep state ({S}) and the previous sleep state nodes will be moved to active state ({A}).

Let ‘a’ be a set of nodes that is transmitting data at time t. Then the node set ‘a’ is said to be in active state, represented as

$$\{a_1, a_2, \ldots, a_i\} :\rightarrow A$$

Let ‘s’ represent the set of sleep nodes that are idle when {A} is active, it is represented as

$$\{s_1, s_2, \ldots, s_i\} :\rightarrow s \text{ where } i \neq j$$

The RE of each node in {A} is computed using equation (5) after each transmission. If the RE of nodes in {A} is likely to be lesser than that of nodes in {S}, then the nodes are swapped between the states. The proposed algorithm selects the path having maximum RE nodes for routing.

Pheromone value here refers to the RE of the nodes visited by the ants. The probability of an ant ‘k’ choosing node ‘j’ from ‘i’ at time ‘t’ (Vallikannu et al., 2015) is given by equation (4)

$$P_{ij}^{k}(t) = \frac{[\tau_{ij}(t)]^{\alpha} \cdot [\eta_{ij}]^{\beta}}{\sum_{l \in N_i^k} [\tau_{il}(t)]^{\alpha} \cdot [\eta_{il}]^{\beta}} \quad (4)$$

where P_{ij}^{k} is the probability of node j to be selected by ant coming from node i, τ_{ij} is the pheromone intensity, N_i^k is the set of nodes and η_{ij} is the prior available heuristic value (RE).

The RE of a node is given by equation (5)

$$RE = E_0 - E_C. \quad (5)$$

where, E_0 is initial energy.

Pheromone values are updated by all the ants that have completed the hop count. The pheromone update of the ants is given by equation (6)

$$\tau_{ij} \leftarrow (1-\rho).\tau_{ij} + \sum_{n=1}^{m} \Delta\tau_{ij}^{n} \quad (6)$$

where ρ is the evaporation rate, m is the number of ants and $\Delta\tau_{ij}^{n}$ is pheromone quantity laid on link (i, j) by the n^{th} ant.

$$\Delta\tau_{ij}^{n} = \frac{1}{H_n}, \text{ if ant } n \text{ travels on link } i, j.$$

where H_n is the hop count of the n^{th} ant.

The ants returning to the source updates the information about their visited path, after the first traversal. As more than one ant is deployed in a random manner to visit each of the neighbour paths, source gains knowledge about multipath to the destination. Optimal path is selected based on higher pheromone values and then ACO passes the solution set to FDR PSO as initial population.

2.4 FDR PSO

FDR PSO optimises energy in the possible paths selected by ACO. The process is carried out in multipath for energy consumption. Successive energy efficient route are selected for transmission. Premature convergence problem of PSO is prevented in FDR PSO by considering n_{best} particle which maximises fitness distance ratio of energy is given by equation (7)

$$\frac{E_c(P_i) - E_c(X_i)}{|P_{id} - X_{id}|} \tag{7}$$

where E_c (P_i) is the energy consumed by the particle in the prior best position, E_c (X_i) is the energy consumed by the particle in the current position P_{id}, is the prior best position of the particle and X_{id} is the current position of the particle.

The velocity update of the i^{th} particle is given by equation (8)

$$V_{id}^{K+1} = (w * V_{id}^{k}) + a_1 r_1 (P_{id} - X_{id}) + a_2 r_2 (P_{gid} - X_{id}) + a_3 r_3 (P_{nd} - X_{id}) \tag{8}$$

Similarly, position update of the particle is given by equation (9)

$$X_{id}^{k+1} = X_{id}^{k} + V_{id}^{k+1} \tag{9}$$

where P_{id} is the best previous position (pbest) of the particle, P_{gid} is the global best position (gbest) of the particle, X_{id} and V_{id} are the current values of position and velocity of the i^{th} particle, a_1, a_2, a_3 are the acceleration coefficients, r_1, r_2, r_3 be the random numbers between 0 and 1, w is inertia weight (Anitha et al., 2009).

2.5 The steps of ACO-FDR PSO is described below

Step1 Initialise ACO parameters.

Step2 Construct ant solution using pheromone trail based on residual node energy with duty cycle using equation (4).

Step3 Pheromone is updated until maximum number of iterations.

Step4 Possible paths are identified by ant agents.

Step5 Population is initialised in FDR PSO based on ACO generated paths.

Step7 Compute fitness function (energy).

Step8 Select pbest, gbest and n_{best} particle for current iteration.

Step9 Update the position and velocity of each particle using equations (8) and (9).

Step10 If maximum iteration is reached, print the energy efficient path. Otherwise go to step 7.

3 Simulation parameters

A network of 1,000 m × 1,000 m region with 100 nodes is considered. Each node pursues RWP mobility model and communicates through a wireless link, connection established through AODV routing protocol. The transmission range of each node is 100 m, with an initial energy of 200 J. 1,500 constant bit rate packets at a rate of 512 Kb each are considered. Total simulation time is 100 s.

4 Results and discussions

The proposed ACO-FDR PSO algorithm is compared with ACO_ALEEP and traditional AODV in terms of throughput, packet delivery ratio, packet drop and RE. The proposed ACO-FDR PSO is verified with the existing methods under variable nodes and variable velocity.

4.1 Impact of varying nodes over network performance metrics

In this simulation, the capability of ACO-FDR PSO is investigated with duty cycle algorithm by varying the number of nodes from 10 to 100. Figure 2 exhibits the throughput, packet delivery ratio, packet drop and RE of the nodes obtained by the proposed algorithm for variable nodes. To validate the results, it has been compared with that of conventional AODV and ACO_ALEEP methods.

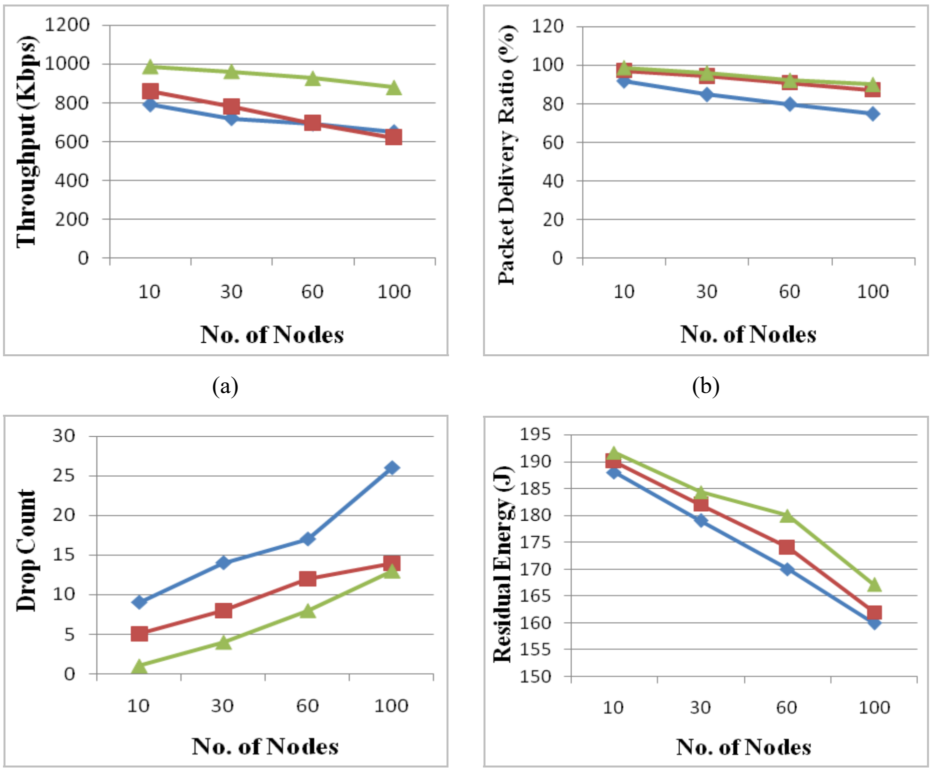
Figure 2(a) shows that the variation of throughput as a function of number of nodes. Results obtained shows that ACO-FDR PSO has highest throughput compared with other two algorithms as increase number of nodes results in increased data transmission between source and destination which maximises throughput.

Figure 2(b) illustrates the impact of nodes over packet delivery ratio observed in the network. Among the three methods ACO-FDR PSO is found to be successful in delivering more number of packets to the correct destination because of prolonged lifetime-based neighbour selection.

The impact of number of nodes over packet drop is demonstrated in the Figure 2(c). Generally when number of nodes increases, the amount of energy consumption also increases that drains the energy of the nodes at faster rates. Node failure increases packet drops in the network. But the investigation of duty cycle algorithm in the proposed method results in selection of prolonged communication sustaining nodes as its next forwarding neighbour by which energy failure of nodes can be minimised that in turn produces lesser drop.

Figure 2(d) shows the impact of nodes over RE. As the number of nodes increases, number of intermediates and the energy consumed by them is augmented. In ACO-FDR PSO, integration of duty cycle switches the nodes between active and sleep state, preventing the node being awake all time. This minimises unnecessary energy drain caused due to interference and overhearing. Successive nodes for data transmission are selected by a set of current active nodes that aids in preserving the energy of the node. Therefore the proposed ACO-FDR PSO holds a higher RE than the existing approaches.

Figure 2 Comparison of ACO-FDR PSO with existing method for variable nodes, (a) no. of nodes vs throughput (b) no. of nodes vs packet delivery ratio (c) no. of nodes vs drop count (d) no. of nodes vs RE (see online version for colours)



(c) (d)

Notes: AODV; ACO-ALEEP; ACO-FDR PSO.

4.2 Impact of velocity over different network performance metrics

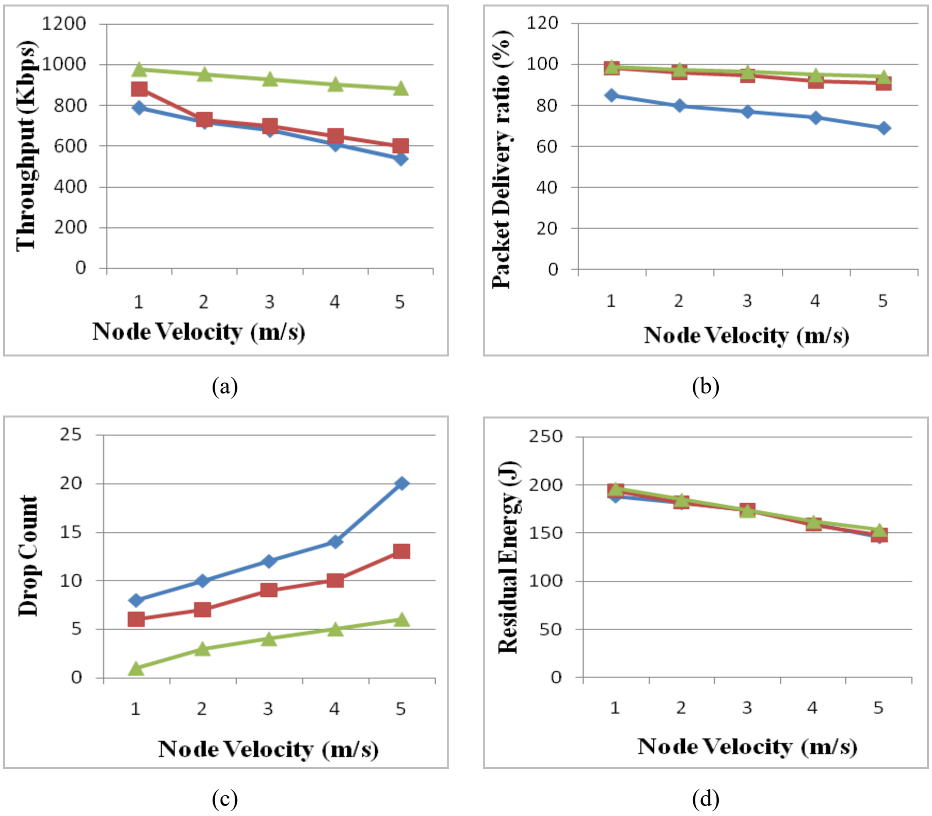
In this simulation study, the performance of the proposed method is examined on varying the mobility of the nodes from 1 m/s to 5 m/s.

Figure 3(a) shows the node's variable velocity and its impact on throughput. As node velocity varies in RWP, link availability is not constant. A selected neighbour does not aid expected transmission by the source as it is dynamic state. In the proposed ACO-FDR PSO, the neighbour is selected considering the available RE; preference for neighbours depends upon remaining energy through which a reliable transmission can be carried out. The mobility of the nodes is less and has lesser impact over the network performance.

The impact of node velocity over packet delivery ratio is illustrated in Figure 3(b). As node velocity increases, link stability between nodes decreases that results in lesser data transfer rates and increased packet drop. The proposed ACO-FDR PSO compensates link stability lag through energy efficient node selection wherein the energy drops are less besides link failure drops. Therefore the proposed method can able to retain higher transfer rates with higher PDR.

Figure 3(c) shows the impact of node velocity over drop count. As the velocity increases link stability and chances for selecting an energy efficient neighbour is low, resulting in packet drop. A network experiences energy drop due to variable velocity. The drop due to insufficient energy of neighbouring nodes is less in the proposed algorithm.

Figure 3 Comparison of ACO-FDR PSO with existing method for variable node mobility, (a) velocity vs throughput (b) velocity vs packet delivery ratio (c) velocity vs drop count (d) velocity vs RE (see online version for colours)



Notes: AODV; ACO-ALEEP; ACO-FDR PSO.

Figure 3(d) shows the impact of velocity over RE. The proposed algorithm based on duty cycle prevents early energy drain through frequent node switching process, conserving the operational energy of a node. The operational energy of the node is prevented from being utilised in overhearing all broadcast process as the node need not listen all the neighbours' broadcast. This helps to conserve an appreciable amount of energy from which the node can be saved from early energy drop. In a dense network, the probability of neighbour switching is high, though the process of duty cycle selects a fewer nodes for operation that aids the nodes to conserve higher RE.

Table 1 shows the comparison of results obtained by AODV, ACO_ALEEP and ACO-FDR PSO techniques with respect to number of nodes.

Table 1 Comparison of various parameters of different techniques with respect to number of nodes

Parameters	*AODV*	*ACO_ALEEP*	*ACO-FDR PSO*
Throughput (Kbps)	540	600	883.9
Packet delivery ratio (%)	69	90.842	93.9
Drop count	20	13	6
Residual energy (J)	146	148	153.25

Table 2 shows the comparison of results obtained by AODV, ACO_ALEEP and ACO-FDR PSO techniques with respect to variable velocities (3m/s and 5m/s).

Table 2 Comparison of various parameters of different techniques with respect to variable velocity (3m/s and 5m/s)

Techniques	*AODV*		*ACO_ALEEP*		*ACO-FDR PSO*	
Velocity (m/s) ⇨ / *Parameters* ⇩	*3*	*5*	*3*	*5*	*3*	*5*
Throughput (Kbps)	680	540	698	600	929.9	883.89
Packet delivery ratio (%)	77	69	94.55	90.84	96.29	93.89
Drop count	12	20	9	13	4	6
Residual energy (J)	173.84	146	174	148	173.14	153.25

5 Conclusions

Energy optimisation in MANETs is tedious tasks as the energy of the nodes is limited whereas communication relies upon the available battery power. The proposed ACO-FDR PSO is a hybrid optimisation approach that considers energy as its fitness function. Through the hybrid approach, ACO selects energy efficient path based on available energy and FDR PSO optimises energy consumed by each nodes. Duty cycle algorithm helps in increasing the lifetime of nodes by swapping nodes between active and idle states. Based on the simulation results, it is being concluded that this proposed algorithm yields 47%, 3.3%, 54% and 3.54% better results for variable nodes than ACO_ALEEP for the performance matrices throughput, packet delivery ratio, packet drop and RE respectively. Similarly 15%, 3.25%, 7.14% and 3.17% improvement has been achieved by the proposed method for throughput, packet delivery ratio, packet drop and RE respectively with variable mobility of nodes than ACO_ALEEP method.

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