Hybrid Energy Efficient and QoS Aware Algorithm to Prolong IoT Network Lifetime

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Abstract. The Internet of Things (IoT) consists of large amount of energy compel devices which are prefigured to progress the effective competence of several industrial applications. It is very much essential to bring down the energy utilization of every device deployed in IoT network without compromising the quality of service (QoS). Here, the difficulty of providing the operation between the QoS allocation and the energy competence for the industrial IoT application is deliberate. To achieve this objective, the multi-objective optimization problem to accomplish the aim of estimating the outage performance and the network lifetime is devised. Subsequently, proposed Hybrid Energy Efficient and QoS Aware (HEEQA) algorithm is a combination of quantum particle swarm optimization (QPSO) along with improved non dominated sorting genetic algorithm (NGSA) to achieve energy balance among the devices is proposed and later the MAC layer parameters are tuned to reduce the further energy consumption of the devices. NSGA is applied to solve the problem of multi-objective optimization and the QPSO algorithm is used to gain the finest cooperative combination. The simulation outcome has put forward that the HEEQA algorithm has attained better operation balance between the energy competence and the QoS provisioning by minimizing the energy consumption, delay, transmission overhead and maximizing network lifetime, throughput and delivery ratio.

Keywords: Energy efficiency · IoT · Network lifetime · QoS

1 Introduction

IoT is considered as the future technology for improving the overall efficiency of the industrial and other applications. IoT in its set up consists of large number of reliable M2M devices having lower communication range [1]. Devices used in IoT mainly uses IEEE 802.15.4 compliant devices with IEEE 802.11ah and LoRaWAN to provide communication with other devices through Internet in order to achieve performance efficiency of the application [2].

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In order to provide cellular network to the local short communication range devices capillary networks are used [3]. Capillary networks help in development of IoT technology by leveraging wireless sensor devices (WSN) to use cellular networks with the aid of gateways in between them. In WSN setup the energy and memory constrained devices are arranged in cluster passion. In clustering process individual nodes residual energy, their distance between base station (BS) and other parameters are considered while choosing the cluster head (CH) of the individual cluster [4]. There may be multiple cluster head in the network but the energy consumption of the cluster head is more compared to normal nodes due the information exchange that they carry out between individual nodes and BS. Capillary network lifetime is described as the time period between capillary network deployment to the residual energy of the first nodes drains completely. Gateways help in connecting these nodes to Internet and to cloud platform to notify in case of emergency or to store the data in cloud platform and also to database.

Cooperative communications is meant to improve energy efficiency, reliability and network lifetime in WSN [5]. Cooperative communication called Reliability Improved Cooperative Communication (RICC), scheme is proposed to maximize the reliability of cooperative communication of the random network in case of multi-hop relay WSN without compromising network lifetime. This method uses residual energy of the node to transmit the data and dynamically adjusts the power required for data transmission based on nodes distance with sink node. Remaining energy alerting mechanism uses Distributed cooperative communication nodes control (DCCNC) mechanism [6], this scheme helps in changing the CH whenever their remaining energy falls below the threshold energy level in order to provide reliable data transfer. Cooperative nodes are used to reduce the overload on the CH and large numbers of cooperative nodes are used in non-hotspot area in order to achieve maximum reliability and lesser cooperative nodes are used in hotspot area to maximize network lifetime. This method drains more energy and delays while choosing CH during clustering process. With an objective of improving network lifetime two sensor solution is provided wherein sensors should collaborate and define how much power is required for cooperation [7]. In case of multiple sensor scenarios network lifetime can be maximized by placing cooperative relays in appropriate location to reduce the power requirement of the nodes thereby relay nodes helps to reduce transmission power required by sensor nodes. This cooperative relay mechanism helps in maximizing network lifetime up to 3 times than normal WSN setup. But to improve QoS of the network requires additional energy and this contradicts network lifetime improvement.

Most of the aforementioned works only concentrates on power control and bit error rate rather than improving network lifetime without compromising on QoS. Thus, HEEQA method is proposed with an objective to maintain balance between energy utilization and QoS in case of clustered IoT setup.

Motivation for doing this work are (1) Energy competence or QoS enlargement to further rate of the energy utilization and multi-objective enlargement problem of the operation among QoS and energy competence to enhance IoT network lifetime. (2) A best supportive combination of cooperative node and CH method can be proposed by means of particle swarm optimization inspired with Quantum (QPSO) collective in the company of comprehensive search. The potential CH candidate is determined by comprehensive search. The short computing, instant and quick convergence, small population size and stronger searching ability can be achieved by QPSO, which combines the evolutionary algorithm and the quantum computing theory. (3) The enhanced non dominated categorization of the genetic method is worn to resolve multi-objective enlargement of QoS and energy competence. The congregate improved in obtaining non dominated sorting compared by evolutionary method (EAs) is capable for the maintenance of a better increase of results in NSGA algorithm, QPSO algorithm calculates the fitness values for the selection of various systems as cooperative nodes.

Overall contribution of this work is outlined as

- Improving the IoT network lifetime by harnessing devices energy consumption during data transmission by optimizing provisioning QoS for energy efficient.
- Quantum particle swarm optimization method is used to select potential CH and cooperative nodes.
- Quantum computing theory which optimizes the computing time can have stronger search for potential nodes and reduces the communication overhead.
- Selection of non dominated set of nodes resulted by using non-dominated genetic sorting algorithm to provide QoS in multi-objective optimization perspective.
- Finally, QPSO and NSGA is combined to form hybrid algorithm called HEEQA to calculate the fitness function for QoS.

The rest of the paper is organized as follows. Section 2 presents a summary of various corresponding works with respect to energy conserving and QoS improvement during routing. Section 3 provides the problem statement of the work. Architecture of the method is presented in Sect. 4. The proposed mechanism and its evaluation is presented in Sect. 5. Simulation and Results and conclusion along with future work are presented in Sects. 6 and 7 respectively.

2 Related Work

Many works have been proposed by authors to improve energy consumed during routing of data which includes [8], where authors have proposed an algorithm called Particle Swarm Optimization (PSO) in which they considered flocking of birds, schooling of fishes, theories of swarm and artificial life or biologically derived algorithm. In this algorithm, the g-best and p-best values are calculated based on the velocity of the PSO for the fitness in hyperspace to obtain optimal solution. The advantage of this paper is that the PSO is capable to coach the group in order to reach ninety two percentage of result and this algorithm is still useful for calculating fitness value. The drawback of this work is that in highly discontinuous data surface features it is difficult to optimize function for local optima. Wu et al. in [9], have proposed algorithm for the pareto order, combine and divide law to shape association sets between entity antenna nodes and to overcome the significant problem of scheming mobile antenna networks with the goal of getting better energy competence. This method can make decision about which communication scheme to be used and which CNs should be attached to which CH. But this method is not suitable in case of super-large scale WSNs setup.

Authors in [10], have proposed an algorithm called LEACH in energy competent with transaction protocol for mobile Micro antenna interconnections. Method uses set of rules defined in LEACH protocol for consistent allocation of energy load along with the nodes in the network on the limited cluster support stations like CH. The data aggregation considerably reduces the total amount of information to be sent to the sink node. LEACH decreases transaction energy eight times compared with straight transmission and also reduces transmission energy during routing. In [11], authors have proposed the novel QPSO method which uses quantum computing theory along with standard PSO in order to resolve spectrum allocation issue in radio and this method provides the global optimal solution when different utility functions are being used. Authors in [12], have proposed algorithm called MOR4WSN which uses NSGA-II to provide multi-objective optimization in WSN routing. This method aims to minimize network energy utilization during the process of sensor distribution.

Task phase organization by shared optimisation of wait with energy competence of capillary device to device interconnections with the 5G transmission model have been proposed in [13]. This method provides development of new energy competent and point to point wait task phase, manages design for guiders in the capillary networks controller with the gateway. It formulates a responsibility cycle to organize difficulty with shared optimisation for energy utilization and point to point wait. The proposed model contains of two parts for the communication plan, first part decides the best possible amount of data to be sent among, gateways, M2M systems and coordinators. Second part is a task phase which manages the IEEE 802.15.4. This method is not suited for large network as the model increases overhead when network size increases. Banka et al. in [14], have proposed PSO-MSPA algorithm which is based on PSO and provides efficient method for placing multiple sink nodes present in the WSN network. This method makes use of Euclidean distance between gateway and sink node and also number of hops in between them to reduce energy during data transfer. But this method lacks in addressing various other QoS parameters which are required in increasing network performance. Authors in [15], have proposed EEPR algorithm which uses probabilistic routing mechanism to control packets requesting routes stochastically during packet transmission to maximize network lifetime and to minimize packet loss rate during flooding. In this method ETX metric is used with AODV protocol to achieve the objective. This method lacks in improving overall energy consumed in the network as this method only controls route request packet amount rate and fails to address different factors which drains network energy faster.

3 Problem Statement

IoT nodes have lower communication range, lesser memory and computational capacity and limited energy capacity. These limitations make IoT nodes to be energy efficient in order to prolong IoT network lifetime.

1. The problem is to find out energy efficient path between the source nodes and the sink nodes using the opportunistic routing without compromising QoS parameters like throughput, reliability and end to end delay.
2. To establish balance between network lifetime maximization and QoS parameters through optimization.

This paper emphasize more on establishing balance between network lifetime and QoS provisioning.

3.1 Lifetime of the Network

The overall energy consumed by the nodes during the process of communication is given by

$$k = K_{u+1}(PN^y) + K_{u+1}(PC^y) \tag{1}$$

where k is the energy consumed by normal node PN during communication and PC represents cluster head. Individual node lifetime is given by

$$LT = \frac{K}{k} \tag{2}$$

where K denotes the residual energy of the node before clustering process. The lifetime of the nodes is a critical factor in increasing the lifetime of the IoT network.

3.2 QoS Stipulation

QoS is stipulated on the basis of successful packet delivery without much packet loss and with less delay. So QoS of the IoT network relies on throughput, reliability and end to end delay without compromising energy efficiency.

– Throughput TH: It is defined as the total number of packets that are successfully delivered to the destination in a unit time.
– End to End delay ED: It is defined as the time that is taken for transferring packets from source to destination in the network.
– Reliability RL: It is the amount of packets that are generated in the source are successfully delivered to the destination.

Throughput during the steady state is given by

$$TH = uP_s PHh \tag{3}$$

where u is the contention probability in which each node independently sends packet, P_s is the probability of successful packet transfer. PH is the particle-hole symmetry and h is the number of nodes.

Suppose if cooperative node is present at the center of cluster head and gateway then it is given by

$$\sum_{i=0}^{h} PH_i = 1 + \frac{h}{2} \tag{4}$$

End to end delay of i^{th} node when $0 \leq i \leq h$ is given by

$$ED = \sum_{i=0}^{h} (uP_s(1 - PH_{i+1}))^{-1} \tag{5}$$

Overall reliability of network is given by

$$RL = \sum_{i=0}^{h} \frac{d_i(1-\xi)}{d_i + \xi - d_i\xi} \tag{6}$$

where ξ is the probability of packet drop and d_i is the geometric distribution.

Reliability of the node i across i to i + 1 link during time slot t_i is given by

$$re_i = (1 - \xi)^{t_i} \tag{7}$$

So the network lifetime and QoS stipulation problem can be formulated as

$$Max \sum_{i=0}^{h} \{LT\} = Optimal\{TH, ED, RL\} \tag{8}$$

4 Network Architecture

In this section, the network model, energy model and route discovery process is presented.

4.1 Network Model

The nodes are randomly deployed and clusters are formed by clustering process, all the wireless devices perform data collection, aggregation and sends to BS or sink.

1. Sink node collects data from the wireless devices, which have a data to be processed.

2. All devices have same transmission range and are energy constrained, IEEE 802.15.4 protocol is used in the radios for shorter communication.
3. Devices can adjust their transmission range to reach particular destinations.
4. Devices are aware of their locations and energy levels.
5. Devices are classified into nodes, CH, cooperative nodes and capillary gateway. Capillary gateway will provide interface to two different radio network types one radio type is used to communicate with local network and other radio type to connect local network to IoT platform as depicted in Fig. 1.

Here two phases of transmission takes place first by forming clusters using the clustering algorithm. The formation of cluster takes place by nodes belonging to one hop distance, so as to communicate within transmission range. CH is elected based on the high residual energy and each device in the cluster updates its location and knows the detail about CH and cooperative nodes. TDMA protocols schedules the transmission of data collected by nodes. CH is responsible to collect data from nodes through data gathering phase. The data gathered form the nodes is aggregated and sent to all cooperative nodes by CH through broadcasting. Then both CH and cooperative nodes forward data to sink node through long distance mode in order to extend the transmission range and also to reduce the load on cluster head.

4.2 Energy Model

Let consider K_0 be the initial energy of every IoT node powered by non-reachable energy source. Energy model of [16], is followed by the nodes in the network. Cluster head CH, one base station or sink node with h number of nodes are distributed. Each node has direction communication between each other through

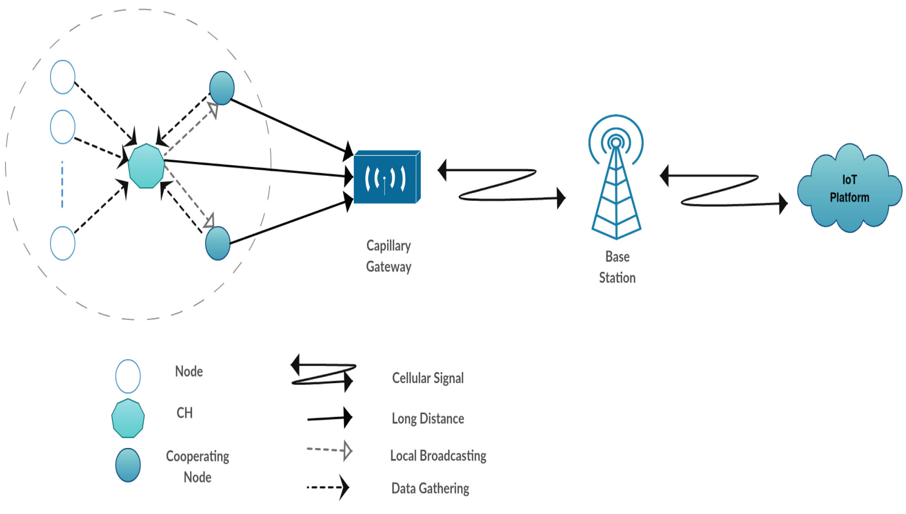

Fig. 1. Network model

radio links within the radio communication range. Every IoT node is uniformly scattered in a terrain of B_t and C_t dimension, wherein i^{th} normal node forwards each packets to the j^{th} cluster head and energy loss while transferring packets between the nodes follows multi-path fading model and free space. Every node in the IoT network consists of transmitter and receiver together called as transreceiver. Energy is dissipated in transmitter by hardware components such as power amplifier and radio components, whereas in receiver energy is dissipated by radio components. Energy is also dissipated during packet transmission and two different models explain this energy dissipation. One model provides for node type whether its head or normal node and other provide based on distance for every packet transferred of size PA_l. After clustering process, the each normal node PN will send data packets to cluster head denoted by PC.

Energy consumed when PA_l bytes of data sent by the normal node is given by

$$K_{los}(PN^y) = K_{elec} * PA_l + K_{fd} * PA_l * ||PN^y - PC^z||^4 \; if ||PN^y - PC^z|| \geq k_0 \quad (9)$$

$$K_{los}(PN^y) = K_{elec} * PA_l + K_{fs} * PA_l * ||PN^y - PC^z||^2 \; if ||PN^y - PC^z|| < k_0 \quad (10)$$

$$k_0 = \sqrt{\frac{K_{fs}}{K_{fd}}} \quad (11)$$

where, K_{elec} is the electronics energy based on factors like modulation, amplifier, filtering and digital coding while, K_{fs} and K_{fd} represents energy of free space and multipath fading model. So the electronics energy is

$$K_{elec} = K_{TRN} + K_{DAG} \quad (12)$$

where K_{TRN} is energy of transmitter and K_{DAG} is energy of data aggregation, $||PN^y - PC^z||$ is the distance between normal node and the cluster head respectively. Each node sends PA_l bytes of data and this sent packet is received by the cluster head. The energy spent by receiver during this process is given by

$$K_{los}(PC^y) = K_{elec} * PA_l \quad (13)$$

Remaining energy of each IoT node is updated after PA_l bytes data is either sent or received

$$K_{u+1}(PN^y) = K_u(PN^y) - K_{los}(PN^y) \quad (14)$$

$$K_{u+1}(PC^y) = K_u(PC^y) - K_{los}(PC^y) \quad (15)$$

This data transfer process continues until every nodes energy becomes zero. The node whose energy is zero is known as dead node.

4.3 Route Discovery Process

The route discovery process works as follows:

1. Routing Information such as source node, destination node and range is taken as an input.
2. Clustering process will takes place and cluster head is selected based on higher residual energy.
3. Nodes will affiliate to corresponding cluster head which is in its range.
4. The neighbor list will be generated which will contain a list of nodes which are within the transmission range of the source node.
5. The source node will then check cluster head whether the neighbor list contains the destination node with minimum distance. If yes then it will stop the routing process since the destination has reached.
6. If the neighbor list does not contain destination node then the next cluster head is picked up to find the existence of destination node with minimum routing distance.
7. Steps 2 through 6 are repeatedly performed until the destination node with optimal routing distance is reached.

5 Proposed HEEQA Algorithm

In HEEQA, QPSO is used to improve the solution of the candidate iteratively to obtain the objective. During this various attributes like present location, local optima, present velocity and global optima are represented by particles. Cooperative selection is made based on the particle present location. NSGA is used to provide find pareto optimal solution based on objective function. The main objective is to improve network lifetime through cooperative nodes in order to improve energy efficiency of the cluster head. The overall HEEQA algorithm is outlined in below steps.

Step 1: Presume each nodes to be cluster head PC successively and employs following steps to choose the optimal cooperative node for the presumed PC.
Step 2: Initiate the population A_p having qp quantum particles on basis of quantum coding mechanism and add it to Pareto front F.
Step 3: Determine every quantum particle through the fitness sort population A_{pf} according to the non dominated Genetic algorithm to find best energy efficient node.
Step 4: Construct a new population A_{pnew} using QPSO algorithm from the existing population A_p.
Step 5: Analyze every quantum particle of the new population A_{pnew} by combining fitness value of both objectives to obtain $\mathrm{A}^*_{pnew} = A_{pnew} \cup A_p$. Classify A^*_{pnew} using NSGA is to provide non dominated solution and assign obtained value to G.
Step 6: Tune up the MAC parameters SIFS, DIFS, CW_{min} and CW_{max} to improve energy efficiency of the nodes.

Step 7: Combine F and G to provide pareto optimal solution set A_{com}.
Step 8: Repeat steps 1 through 7 to find A_{com} of each iteration and add these values for every PC to obtain A_{final}. Classify A_{final} in descending order using NSGA with respect to crowding distance and find optimal solution from sorted A_{final}.

6 Simulation and Results

6.1 Simulation Model

The proposed HEEQA algorithm is evaluated extensively using event driven network simulator NS-2 simulator. The simulation is done on a terrain size of 500 m × 500 m with 30 to 50 nodes deployed randomly with an initial energy of 60 J. The transmission range of the node is set to 250 m. Parameters used in the simulation are given in Table 1. Here, we have compared proposed method with QPSO due to the prevalent functionalities between each other.

6.2 Simulation Results

In this section the performance of the algorithm with respect to residual energy maximization, end-to-end delay, packet delivery ratio (PDR), transmission overhead, network lifetime maximization and throughput is evaluated.

6.3 Variation of Energy Level

Proposed method is efficient in saving the energy of the nodes due to the presence of cooperative node between cluster head and the gateway node which reduces the energy consumption of the node drained during data transmission. The Fig. 2 shows the efficiency of the HEEQA when compared with QPSO.

Table 1. Simulation parameters

Parameter	Value
Number of nodes h	50 nodes
Network size $B_t \times C_t$	500 m $*$ 500 m
Transmission range	250 m
Initial energy K_0	60 J
Propagation model	Two ray ground
Number of rounds	100
Packet size	250 KB
Traffic type	CBR
MAC type	802.11
Antenna type	Omni directional antenna
Examined protocol	HEEQA and QPSO

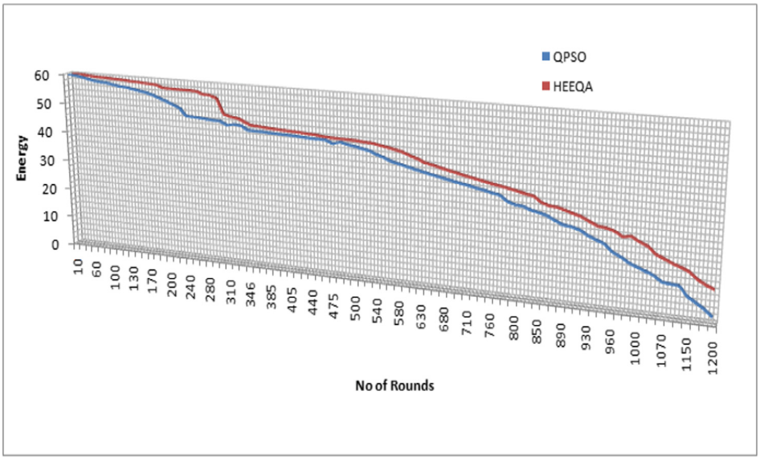

Fig. 2. Residual energy

6.4 Average End-to-End Delay

It is very important for any method to minimize end-to-end delay of the data packets else the reliability of the network decreases. Reduction in end-to-end delay will results in better throughput. In this method data packets are delivered faster due to the use of long distance communication method. Figure 3 provides comparative graph of end-to-end delay.

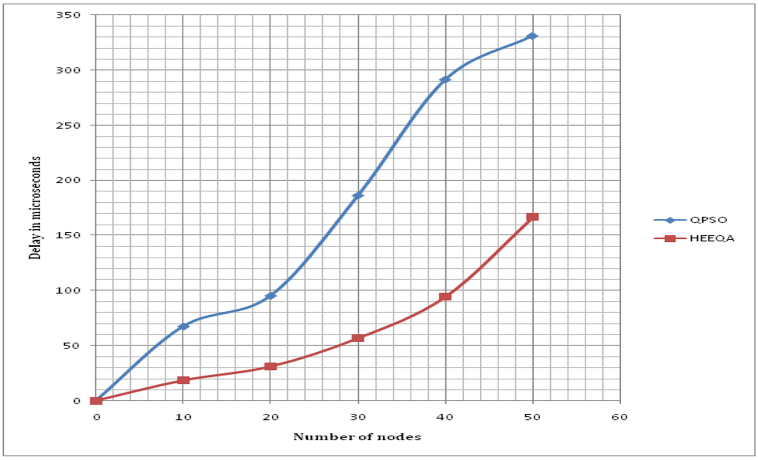

Fig. 3. Average end-to-end delay comparison

6.5 Delivery Ratio

Figure 4 provides the increase in packets delivery ratio achieved by the proposed method. This method achieves notable amount of PDR when compared to QPSA due to presence of cooperative nodes which aid in faster delivery of data packets along with cluster head in long distance mode which avoids congestion in the route due to less channel occupancy.

6.6 Transmission Overhead

Transmission overhead will have negative impact on the overall network lifetime due to the congestion in the transmission route and results in frequent change in the cluster head due to lesser residual energy. Figure 5 shows proposed method outperforms in terms of transmission overhead reduction which is resultant of optimal usage of cluster head residual energy.

6.7 Network Lifetime

It is observed in the Fig. 6 that as the density of the nodes increases then the proposed method outperforms than the QPSO method. Due to different threshold level in outage probability the lifetime of the IoT network increases. It is due to the fact that outage probability provides average unsuccessful rate in transmission by setting up threshold level in the signal to noise ratio. Another factor for improving network lifetime is the use of long distance communication which is about 250 m and this communication method aids in increasing the overall lifetime of the cluster head.

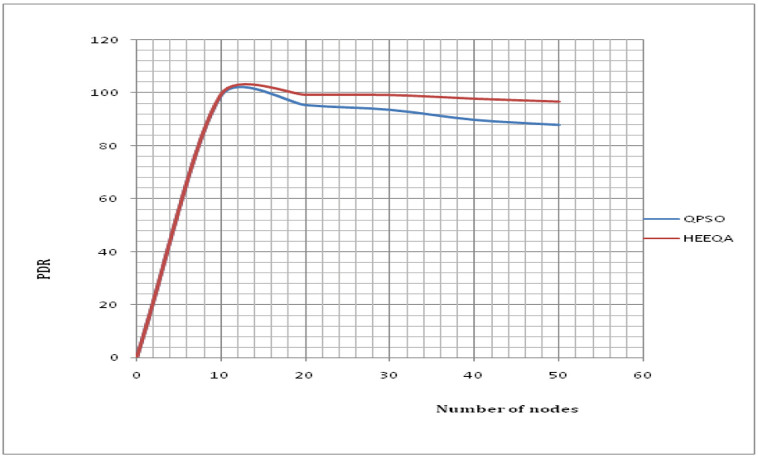

Fig. 4. Packet delivery ratio

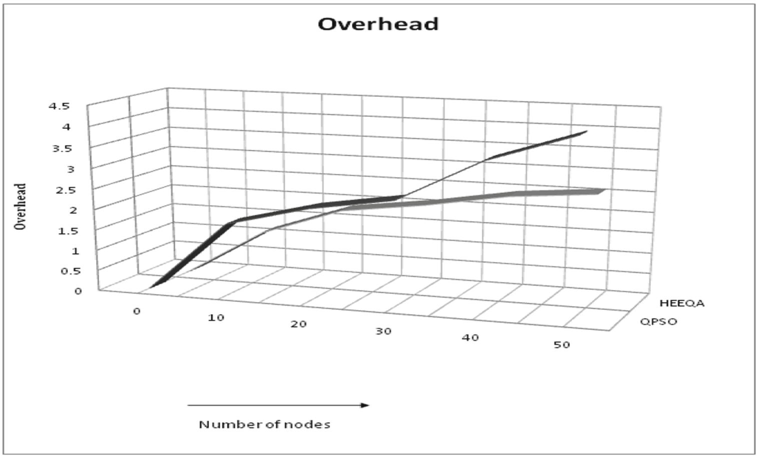

Fig. 5. Comparison of transmission overhead

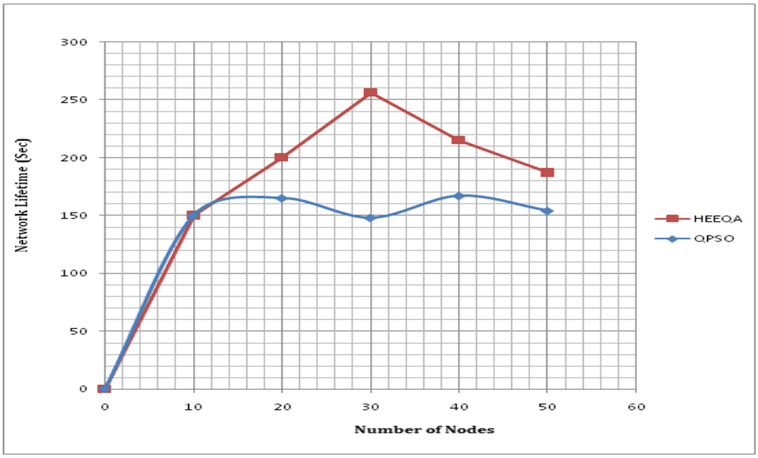

Fig. 6. Network lifetime comparison

6.8 Network Throughput

Network throughput comparison in Fig. 7 and Fig. 8 provides the amount of data successfully delivered in case of 30 and 50 nodes respectively. Throughput of the network is better compared to QPSO due to lesser end-to-end delay and optimal use of residual energy of the nodes, which helps in successful transmission of data. Increase in residual energy of the individual nodes and cluster head will maximize the network throughput due to decrease in dead nodes.

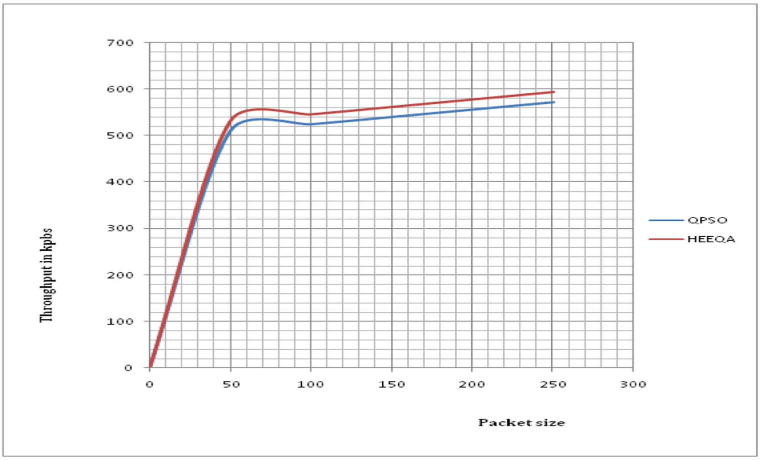

Fig. 7. Throughput comparison for 30 nodes

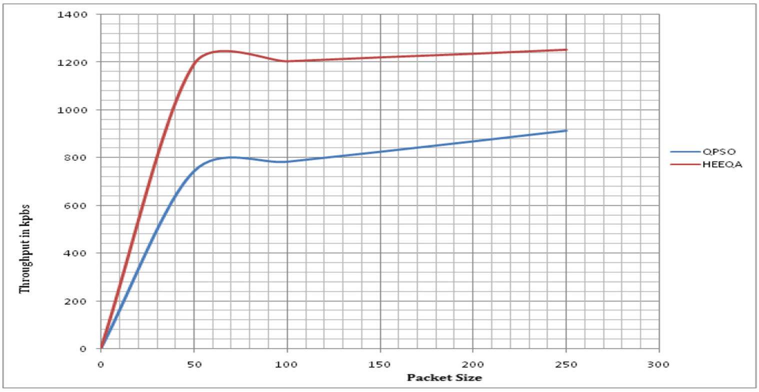

Fig. 8. Throughput comparison for 50 nodes

7 Conclusions and Future Work

Achieving QoS in IoT devices is a major challenge and to prolong lifetime of the devices requires energy balancing. In this paper HEEQA is proposed, which is an energy competent QoS aware model by combining NSGA and QPSO to find the best fitness node with high residual energy for energy efficient communication among the cluster. With the simulation results we have showed that: (i) Use of cooperative nodes will increase the efficiency of cluster heads in terms of optimizing QoS and overall QoS performance is increased due to long communication mode. (ii) Energy consumption of each node in the IoT network is reduced by tuning up of MAC layer parameters. (iii) Proposed method outperforms QPSO in terms of residual energy maximization, end-to-end delay, delivery ratio, transmission overhead, network lifetime maximization and throughput. However the proposed method will have poor performance in terms of energy conservation when nodes are mobile with different moving speed.

Future work in terms of improving proposed work includes improving energy efficiency of the method for higher throughput in case of larger network. The proposed HEEQA can also be made more energy efficient by excluding redundant data during routing.

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