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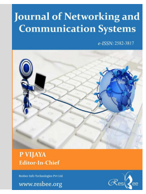

Scheduling-based Atom Search Bat Optimization for Energy-Constrained and Delay Sensitive Wireless Sensor Networks

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Abstract: Over the past decades, the Wireless Sensor Network (WSN) has reached greater heights. The main challenge in the WSN is the handling of the traffic load in the network without the reduction in the energy efficiency of the network. In this research, a scheduling algorithm is developed in the MAC protocol for energy constraint and delay sensitive WSN. The scheduling algorithm is developed using the proposed ASBAT-MAC protocol, which is developed by integrating the Atom Search Optimization (ASO) and Bat algorithm (BA). The scheduling is carried out based on the fitness function by considering the factors, like delay, energy, and fairness. The conception of the distributed energy fair scheduling MAC protocol and the residual energy is provided by the scheduling algorithm for the nodes to maintain a residual-energy queue in the node of the neighbour so that the network overhead is avoided and energy consumption is reduced. The simulation of the proposed ASBAT-MAC protocol is done based on the performance metrics, such as number of alive nodes, Fairness, Normalized energy and Throughput for nodes 50, 100 and 150 by varying the number of rounds. The proposed ASBAT-MAC protocol obtained a maximum number of alive nodes of 94, maximum fairness of 0.3520, maximum normalized energy of 0.1339 and maximum throughput of 0.5933, respectively for 150 nodes when compared with the existing protocols.

Keywords: Media Access Protocols, Residual Energy, Scheduling, Sensor Nodes, Wireless Sensor Network.

1. Introduction

WSN has become one of the most significant technologies in the past decades. In WSN, tiny electronic devices, known as sensor nodes are formed by integrating data processing, automated sensing, and wireless transmission units. The sensor nodes in the WSN are capable of computation, sensing and communication. The sensor nodes sense the data from the surrounding environment, forward it to the central node through multiple paths after collecting the data from one or more physical phenomenon for further processing [2]. WSN are utilized in different applications, like agriculture, healthcare, industrial automation, military surveillance, smart cities and disaster management due to the advancements in the wireless networking technologies and micro-electro-mechanical systems (MEMS). From the above domains, the most promising field for the implementation of the smart monitoring is the prevention of the serious disasters, like chemical gas leakage, fire and the monitoring of the environment parameters for the application in agriculture. The primary requirement in WSN for monitoring application is the energy efficiency. Other primary constraints considered in the WSN are latency, energy efficiency and reliability, which is required to provide the QoS assurance for the emergency data traffic, such as information of the fire in the fire monitoring service, information of the alarm in the medical rescue service and the emergency alarm in the detection of hazardous gas [1].

In the traditional WSN applications, the primary importance is the emergency efficiency as it has major influence in prolonging the lifetime of the network, whereas the secondary importance is given to the QoS constraints, like delay constraints and bandwidth. The flow of the vehicular traffic on highways is monitored using the current multimedia applications of WSN for real-time and reliable detection of events. High probability of the packet collision and channel contention is caused as huge volumes of data are produced in these applications in a short period of time [4]. With the support of the mobile base station or the mobile sink, theenergy efficiency of the WSN is achieved. In the mobile base station, the sink node moves around the network [6] [14]. The phases suggested for the effective routing are the random selection of CH, configuration of the network, free association, natural selection of CH and scheduling of data [6]. Numerous MAC Protocols are designed for WSNs with the objective to improve

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the scalability, energy efficiency, throughput and scalability. The bursty traffic is generated by the healthcare applications that require high throughput, low delay and high delivery rate [4]. For the purpose of improving the WSN performance, the Media Access Protocols (MAC) is widely targeted by the researchers[7].

Various researches are proposed in the past decade for prolonging the network lifetime of the sensor nodes. The duty cycling strategy is one of the methods used for improving the network lifetime. In the duty cycling strategy, the different units of the sensor node enters the low-power mode or the switched off mode while they are inactive [6] [14]. Other approaches such as, routing protocols and energy-aware medium access control protocols (MACs) are developed for improving the network lifetime [6] [13]. In the MAC protocol, the Quorum slots are assigned for locating the nodes far from the sink node. Sleep wake scheduling is also designed with the MAC protocols in WSN [6]. The number of packets transmitted in the network is reduced by removing the packets containing the redundant data in the same region using the data aggregation and fusion method [2] [9] [10]. Although the previous solution reduces the consumption of the energy besides increasing the time period between the battery replacements for extending the lifetime of the network, it failed to resolve the problem completely. The energy limitation of the sensor nodes is overcome by exploiting the wasteful energy surrounding the nodes into electrical energythat supplement the storage device and the power sensor node directly, which is commonly referred as power scavenging or energy harvesting [2] [11] [12]. The transceiver activity and the protocol design of the MAC determined the characteristics of an energy harvesting circuit. Thus, the cost of the harvesting circuit is minimized using an efficient MAC protocol [2].

The main contribution of the research is the design and development of the scheduling algorithm in MAC protocol in energy constraint and delay sensitive WSN. The scheduling is carried out using the proposed ASBAT optimization algorithm, which is the integration of the ASO algorithm and Bat algorithm. The scheduling is done based on the fitness function by considering the factors, like delay, energy, and fairness. The energy efficient MAC protocol developed helps in coordinating the access of the nodes to the shared wireless medium for maximizing the throughput and reducing the collisions significantly.

The organization of the research is as follows, section 1 introduces the MAC protocol, section 2 reviews the existing MAC protocols, section 3 describes the system model of the dealy sensitive WSN, section 4 explains the proposed ASBAT-MAC protocol, section 5 discusses the result of the proposed ASBAT-MAC protocol and section 6 concludes the paper.

2. Motivation

This section describes the literature survey of the existing MAC protocols in WSN along with the disadvantages. The challenges of the existing MAC protocols are also discussed in this section.

2.1 Literature Review

Kaur, T. and Kumar, D [1] developed a Energy Traffic Priority Scheduling-based QoS-aware MAC Protocol. Although this method provided improvement in the average delay during transmission, total transmitted data and the consumption of energy associated with sensor nodes, it failed to accomdate the idle data slots. Al-Sulaifanie, A.I et al. [2] designed a Adaptive Hierarchical MAC (AH-MAC) Protocol. This method provided improvement in throughput, consumption of energy, balancing of load, overhead traffic in the network and cross-layer optimization. However, the cost of the harvesting circuit was high in the AH-MAC as it required high storage capacity. Liu, Y et al. [3] modeled a Quorum time slot adaptive condensing (QTSAC)-based MAC protocol. Although this method enhanced the lifetime of the network and the energy efficiency, it had high end to end delay. Swain, R.R et al. [4] developed a Energy Efficient Advertisement Based Multichannel Distributed MAC Protocol. Although this protocol achieved better energy efficiency, it supported single data rate only.

Singh, R et al. [5] designed a Joint Routing and MAC Protocol (JRAM) for reducing the delay in the transmission. This method reduced the consumption of energy during the periodic broadcast of the information required for the maintenance of the synchronization and topology. It also provided better solution while reporting the delay sensitive events to the sink. However, this method high computational complexity. Movva, P. and Rao, P.T [6] modeled a ring partitioned based MAC scheduling (RP-MAC) for energy efficient routing. The RP-MAC protocol improved the lifetime of the network by minimizing the consumption of the energy in all possible ways. However this protocol failed to evaluate the system with large number of sensor nodes. Siddiqui, S et al. [7] developed a Adaptive and Dynamic Polling based MAC (ADP-MAC) Protocol. This method provided better performance interms of delay, energy and packet loss. However, the increasing mismatch in the channel polling and preamble transmission degrades the performance. Kang, M.W. and Chung, Y.W [8] designed an Energy-aware routing protocol.

Although this protocol provided better overhead ratio, delivery probability, and alive node ratio, it failed to decide the network parameters dynamically in the varying network.

In 2023, Chu *et al.* [23] have presented IRIS light-weight long-range WSN. Initially, the nodes discover the nearby node with the high signal strength to establish the communication between the node links. Then the low and medium signal was controlled through IRIS to stop unnecessary transmission to the nodes. Furthermore, a routing algorithm based on adaptive path selection and hop count limit was employed by IRIS for efficient data packet delivery. IRIS also maintains robustness evenly in difficult conditions. Finally, the performance was evaluated through various network topologies and validates the results. In the end, the process was practically implemented. The result showed that the process was reliable, energy-contained, and cost-efficient.

In 2023, Zeng *et al.* [24] have enabled pre-Awake for wake-up radio enable a sensor-based system (PA-WuRES). The network model consists of sensor nodes and Wake-up Radio (WuR) enable nodes that were used to create a routing path for data transmission. The routing path was the path taken by the data from the sensor nodes to the destination. The flight path refers to the path taken by the data during transmission. Sensor nodes were small devices that were used to collect data from the environment. WuR enables nodes that were equipped with Wake-up Radio technology, which allows them to wake up other nodes in the network only when necessary, thus saving energy. The routing path was the path taken by the data from the source node to the destination node. The flight path is the actual path taken by the data during transmission, which may differ from the routing path due to factors such as interference and congestion. The result showed it required less deployment cost and work on minimum energy. However, the project did not experiment practically.

In 2023, Kalaivannan*et al.* [25] have used T-based Routing Topology (TRT)with a lesser number of nodes to search more areas accurately. This method was cost-efficient and highly accurate. Initially, WSN was deployed in the affected areas. The different nodes of the WS collect the data from the site. Then TRT communicates the data from the nodes to the base stations. The data were analyzed in Network Simulator-2 (NS-2) to predict the meticulous location of the thread. This method provides accurate information with fewer human resources. However, the deployment site required high equipment and power supply.

In 2023, Dev, J. and Mishra, J [26] have introduced Energy Efficient Object Detection and Tracking Framework (EEODTF). Initially, this method optimizes the mobile nodes with less power consumption. Next, the Mobile Node Trajectory method was used to track better coverage from the sensor. Meanwhile, clusters were formed to reduce the communication among the nodes in minimized energy consumption. Then the collected data were reported through a better path selection method. Finally, Ml was used to effectively optimize the detected result. The results were further tested with other existing models to predict the effectiveness of EEODTF. However, this project had not experimented with real-world scenarios.

In 2023, Zheng *et al.* [27] have experimented with multi-objective particle swarm optimization and Fuzzy C. Initially, the process starts with the clustering of networks and determining the optimal number of each cluster head (CH) using the algorithm fuzzy c. Then from the CH two CH were selected using multi-objective particle swarm optimization (MOPSO). After that, Mobile Sink's ideal trajectory was determined after selecting the CH using Ant Colony Optimization Algorithm (ACO). Finally, the result was evaluated and compared against other algorithms to determine its effectiveness in reducing energy consumption while minimizing acquisition delay by mobile sinks within wireless sensor networks.

In 2022, weber *et al.* [28] have implemented Clustered WuRx in WSN. Initially, the network was separated into clusters with fog and sink nodes. Each node in the cluster was maintained by a fog node. When any information is needed in the sing node, the multi-cast wake-up mechanism awakens the intermediate nodes and the route was established. Finally, the information was shared with the end node. The experimental result proved that this method was highly efficient than other routing protocols.

In 2022, Dogra *et al.* [29] have executed an intelligent 5G MIMO protocol for enabling better transmission of data in IoT networks. Initially, a network was initialized with its sensor nodes and their locations. In the next step the cluster head was selected from the nodes based on the distances, number of immediate notes, and energy consumption. The data from the sensors were aggregated with the CH to minimize unnecessary transmission in the network. Then the aggregated signals were provided a signature through the public key cryptography technique to maintain authenticity. The authenticated signals were further transmitted in hops. Meanwhile, MIMO was used for multiple transmissions and receiving of signals. The QoE metrics were assigned to maintain the quality of the transmission. This method improved the robustness of transmission and eliminates hotspot problems. However, this method was not practically implemented.

In 2023, Kaur *et al.* [30] have adopted EEWBP to resolve the issues in WSN. Initially, EEWBP created metrics with node degree, outstanding energy, a total of nearby nodes, trust value, and speed. This helps to build the cluster and evaluate the nodes through the scheduling process. After evaluation, the parameters of the sensors will be added to form a cluster with the exerted weight. Then CH was assigned and data were transmitted at less cost and energy.

2.2 Challenges

The challenges prevailing in the existing MAC protocols are as follows,

- The density of the node increases as the use of WSN becomes pervasive, which leads to new challenge for the MAC layer protocol design [4].
- One of the important issues in WSN is meeting the requirements of the application that has low consumption of energy, low latency, high responsiveness and high throughput [7].
- The energy should be optimized in every aspect to prolong the lifetime of the network. The consumption of the energy is still an important challenge as the development of electronics with reduced size has lead to the development of low-power and low-cost sensor networks [2].
- Maintaining the required bit error rate is a challenging task in low-power WSN as the conditions of the channel are time-variant [13].
- In the MAC protocol, the main challenge is the energy efficiency. Some devices works unobtrusively for months or years despite the low battery power of the body sensor. Thus, the packet overhead, energy wastages, collision, overhearing should be mitigated.

3 System Model of the Delay Sensitive WSN

The system model of the delay sensitive WSN consists of wireless nodes moving in a fixed area. The detailed description of the network and the energy model are given below:

3.1 Network Model

The network model used in the proposed ASBAT-MAC protocol is the delay sensitive network. For example, the device embedded in the bus or held by the human is considered as a node. According to the strategy, the messages are forwarded in the network. If the route exists already, the message is forwarded between the sender and the receiver using the standard routing protocol. This mechanism is known as, synchronous routing. During the absence of route, the message is forwarded to the node using the asynchronous routing mechanism with high chance of message delivery rate. Until the route is established with the receiver or the forwarding node e_o, the message is stored by the node e in its local buffer, which has the higher chance of message delivery. In the synchronous routing, the message is delivered from the e to r, whereas the message is forwarded from e to the e_o with the asynchronous routing. Until the message reaches the final destination (receiver), the routing process continues. However, the limited size of the buffer causes message loss in the delay sensitive network mechanism. This limitation of the delay sensitive network mechanism is overcome using unlimited size of the buffer. The delay sensitive network management system has different message replacement and buffer management policies [20].

One of the major issues in asynchronous routing is the selection of the forward nodes [21]. This limitation is overcome by the Context Aware Routing (CAR) [22]. Based on the context information, the node calculates the delivery probability, which is the successful delivery rate of the message. The system aspects that drive the message delivery process using the set of attributes is known as node context. The utility function, $W(x_i, x_2, ..., x_n) = \sum_{i=1}^{n} u_i W_i(x_i)$, where the attributes are represented as x_i, the utility function measured over x_i is denoted as, $W_i(x_i)$ and the significance weight that reflects the importance of the attribute is denoted as, u_i. The estimation of the delivery probability of its own is periodically computed by the node. Then, the estimation is broadcasted to all the nodes that can be reachable through synchronous routing. The information is attached to the delivery probability estimation for building the routing tables. The DSDV is employed as the synchronous routing protocol by the CAR. In the CAR, the message is delivered by selecting the forward node that has high chance of message delivery i.e., the node with the highest value of W [17].

3.2 Energy Model

The energy model of the protocol is discussed in this section. The total energy consumed while transmitting an L-bit message at distance, A by the radio of the sensor node is given as,

$$F_{TX}(H,A)=(H)F_{elec}+(H)F_{amp}\times A^2 \quad \textbf{(1)}$$

where, F_{amp} and F_{elec} are the energy dissipation in the amplifier and the electronics circuit of the radio model respectively [1]. The total energy consumed while receiving an L-bit message at distance, A by the radio of the sensor node is given as,

$$F_{RX}(H)=(H)F_{elec} \quad (2)$$

During the setup phase, the total energy consumed by cluster head, B is given as,

$$F_B^{PS}=F_{TX}(H_{BAdv},A_{B(max)})+(D)F_{RX}(H_{JM})+F_{TX}(H_{BAdv},A_{B(max)}) \quad (3)$$

During the setup phase, the total energy consumed by member node, MN is given as,

$$F_j^{PS}=F_{RX}(h_{BAdv})+F_{TX}(h_{JM},d_{(j,b)})+F_{RX}(h_{AC}) \quad (4)$$

Thus, the total energy consumed in the setup phase, PS is given as,

$$F^{PS}=F_B^{PS}+\sum_{j=1}^{D}F_{MN_j}^{PS} \quad (5)$$

During the steady-state phase, the total energy consumed by cluster head, B in the i^{th} of the intra-cluster communication is given as,

$$F_B^{SPS_i}=(m)F_{RX}(H_B)+(D-m)F_{idle}(H_B)+E_{TX}(H_{RSA}\cdot A_{B(max)})+(m)F_{RX}(H_{RP})$$
$$+F_{TX}(H_{DSA}\cdot A_{B(max)})+\sum_{j=1}^{m}(AC_j)F_{RX}(H_{DP}) \quad (6)$$

During the steady-state phase, the total energy consumed by member node, MN in the i^{th} of the intra-cluster communication is given as,

$$F_j^{sSPS_i^{int\,ra}}=F_{TX}(h_{CB},d_{(j,b)})+F_{RX}(h_{DSA})+F_{TX}(h_{DP},d_{(j,b)})+c_j F_{TX}(h_{DP},d_{(j,b)}) \quad (7)$$

Thus, the total energy consumed in the steady-state phase, SPS that contain r sessions of round is given as,

$$F^{SPS}=\sum_{i=1}^{r}(F_B^{SPS_i}+\sum_{j=1}^{m}F_{MN}^{SPS_i})+F_{Inter}^{SPS} \quad (8)$$

Table 1: Notations used in the proposed ASBAT-MAC protocol

Symbol	Description
D	Set of sensor nodes
MN	Set of member nodes
B	Cluster heads
JM	Joint request message
DM	Data slot allocation message
DP	Data packet
$d_{(j,b)}$	The distance between MN and its corresponding B
Q_b^{BAdv}/Q_j^{BAdv}	Power consumed by the B/MN while broadcasting /receiving the B_Adv message
Q_b^{JM}/Q_j^{JM}	Power consumed by the B/MN while broadcasting /receiving the Joint_Request message
Q_b^{CB}/Q_j^{CB}	Power consumed by the B/MN while broadcasting /receiving the Control_bit message
Q_b^{CS}/Q_j^{CS}	Power consumed by the B/MN while broadcasting /receiving the CS_Allocation message
h_{AC}	Allocation message size
PS	setup phase
SPS	Steady-state phase
$A_{D_s,BS}$	Euclidean distance between the sensor node and BS
R_{BAdv}	Time required to transmit/receive the B_Adv message
R_{JM}	Time required to transmit/receive the JM

R_{CB}	Time required to transmit/receive the control packet
R_{CS}	Time required to transmit/receive the CS_Allocation message
R_{DSA}	Time required to transmit/receive the DM
R_{DP}	Time required to transmit/receive the DP
c	Number of slots of data allocated to MN
h_{BAdv}	Size of B_Adv message
h_{JM}	Size of JM
h_{CB}	Size of control packet
h_{DSA}	Size of DM
h_{DP}	Size of DP

3.3 Transmission Delay Model

Transmission delay is evaluated as the time when the source node has a reservation request till the time data has reached the cluster head successfully. The maximum transmission latency in proposed ASBAT-MAC protocol is given as:

$$R_{TD} = (D) \times R_{CB} + R_{RSA} + (D) R_{RS} + R_{DSA} + m \times c \times R_{DS} \tag{9}$$

where, time required to transmit/receive the request slot allocation message is represented as R_{RSA}

4. Proposed ASBAT-MAC protocol for scheduling the data packets

This section discusses the scheduling based MAC protocol for delay sensitive WSN. The proposed ASBAT-MAC protocol has several round of which each round has setup phase (PS) and steady-state phase (SPS).

4.1 Set Up Phase

The setup phase consists of the proposed ASBAT-MAC protocol consists of CH selection based on ranks, cluster formation and TDMA schedule allocation. In the setup phase, the position in reference to BS and the current availability of the energy is considered for the election of CHs from the potential nodes. The CHs selection is done using the node rank algorithm. The node rank algorithm considers the node having the highest residual energy and the shortest distance as the highest rank node and assigns them as the CHs.

4.1.1.Cluster Head Selection

The optimal CHs are selected for transferring the data in every round [18]. The advantage of using theFABC algorithm for the selection of CHs is that this algorithm reduced the delay and the consumption of energy with optimal routing. The steps followed for the selection of the CH using the Multi-objective fractional artificial bee colony algorithm is as follows,

1. Initialization of the energy

The first step is the initialization of the energy of the sensor nodes. The sensor nodes within the network are located and the energy is initialized for all the sensor nodes in the network. The centralized clustering-based routing strategy is done by determining the location of the sensor node at the sink node. The CHs are identified for grouping the sensor nodes such that the data is gathered periodically. The identification of the CHs is done through the Multi-objective fractional artificial bee colony (FABC) algorithm.

2. Selection of CHs using FABC

In the FABC algorithm, the food source length is equivalent to the required number of cluster head. The food source ranges from integer '1' to the total number of nodes in the simulated network. The index of the sensor node is the elements of the food source. Initially, the food source is initialized randomly within the search space. With the help of the fitness function, the food source is evaluated. If the fitness function of the new source is minimum than the old one then, the old source is considered, whereas if the fitness function of the new source is maximum than the old one, then the old food source is replaced with the new one. Finally, the best CHs are memorized and then the CHs update the energy of the node.

3. Termination

The final step is the depletion of energy and termination. The communication between the cluster heads and nodes are executed after the identification of the cluster head. The energy depleted at every node for every byte of data transfer is explained in the energy model. Both the executed for d number of rounds until all the node become dead.

4.1.2. Cluster Formation

Once the BS selects the optimal B s, a small advertisement message is broadcasted by B to introduce itself to the network. The non-CH node k sends JM to the CH after receiving more than one advertisement messages. Usually, the non-CH sends joint request message to the CH with the higher rank value.

4.1.3 TDMA Schedule Allocation

After receiving the joint request messages from the elected CHs, the nodes are evaluated followed by the allotment of TDMA schedule for intra-cluster communication. The TDMA schedule message is broadcasted to the member nodes by the CHs. The TDMA schedule message consists of duration of the frame, frame control, allocated one-bit control slot number, number of frames, frame check sequence and total number of control slots. The schedule message length is proportional to the number of member nodes in the cluster. The nodes receive information regarding the termination of the setup phase and steady-state phase from the assignment message.

4.2. Steady State Phase

The Steady state phase of the proposed ASBAT-MAC protocol consists of data transmission. In the data transmission phase, the sensed data packets are routed to the BS by the nodes.

4.2.1 Intra-Cluster Communication

The communication between the CH and its member nodes are through multiple frames/sessions in the Intra-cluster communication. One session of the ETPS-MAC protocol consists of control period (CP), Reservation request period (RRP) and the data transmission period (DTP) respectively.

4.2.1.1. Multiple Frame-Based Communications

In this protocol, the CP is divided into E control slots of fixed size, where E is the member nodes of the cluster. During the allocated slot, the source nodes transmit one-bit control message for reserving the request slot, or else the radio is kept off by the nodes during CP. The idle consumption of the energy of CH is reduced by the CP in the RRP. Prior to the transmission of data, the slot scheduling takes place in the ASBAT-MAC protocol protocol, which is facilitated by RRP. The control slots are divided into E request subslots with fixed size. The request slot allocation (RS_Alloc) message is broadcasted to the member nodes by the B based on the control messages received. RS_Alloc message consists of allocated request slot, frame control, member node ID, frame check sequence (FCS) and total number of request slots. Then, B receives the a Data_Req frame from the source member node and stores the information in the node information list (NIL) during the allocated request slot. For the non-allocated request slots, the radio is kept OFF. In the SPS, the event that is happened is captured by the sensor node and stored in its associated network queue as packets. Each node checks the information regarding the network queues and the residual energy that remain in the buffer for transmission prior to the request frame transmission. Then, the information is stored in the request frame.

4.2.1.2. Proposed ASBAT Optimization Algorithm for Scheduling

This section describes the scheduling mechanism using the proposed ASBAT-MAC protocol. The proposed ASBAT-MAC protocol is developed by integrating ASO [16] and Bat algorithm [15]. The bat algorithm considers the behaviour of echolocation in bats. The bat finds and discriminate the prey even in complete darkness due to the echolocation behaviour. The ASO was developed based on the atomic motion model. The diverse set of problems in the optimization is solved using the ASO algorithm. Thus, the ASBAT-MAC protocol considers the advantage of both optimization algorithm for effective scheduling. In the ASBAT-MAC protocol, the velocity from the Bat algorithm is applied to the ASO for updating the position thus, leading to the effective determination of the best solution for scheduling.

1) Solution Encoding

The solution of the proposed ASBAT-MAC protocol is determined using the solution encoding. The scheduling of the data packets between the nodes is the solution of the protocol. The nodes are assigned based on the priority that depends on the energy, delay and fairness. Fig.1 shows the solution encoding of scheduling between the nodes in the cluster. Here, 8 index of the nodes in the cluster are considered and they are scheduled based on the priority.

4	2	1	…………………	8

Fig.1. *Solution encoding*

2) Fitness function

The fitness function in the proposed ASBAT-MAC protocol is calculated using the following equation,

$$F = (E_i + D_i + (1 - F_i)) * \frac{1}{N} \tag{10}$$

where, N is the normalizing factor and D_i is the transmission delay from the node i to its CH and E_i is the energy consumption of the i^{th} node in the j^{th} cluster. F_i is the fairness, which is equal to the proportional fairness, Maximum throughput and Mixed bias fairness []. In the proportional fairness, the allocation of the resource is based on the network characteristics, such as Bit Error Rate, Signal-to-Noise Ratio, throughput and distance. The proportional fairness is given as,

$$S = \frac{1}{\xi^{\gamma}} \tag{11}$$

where, the allocation of the resource to the source through proportional fairness is denoted as S, the proportionality factor is given as, γ and the ξ is the priority characteristics. The mixed-bias allocates portion of the resource using a strongly biased policy and the remaining portion using a strongly biased policy.

$$S_M = \frac{\alpha}{\Re^{b_1}} + \frac{(1-\alpha)}{\Re^{b_2}} \tag{12}$$

where, the probabilistic factors are represented as, b_1 and b_2. $\alpha \geq 0$ and $\Re$ is the characteristic of the mixed biasing. In the maximum throughput, the resource is allocated to the node that transmitted the data faster [19].

3) Algorithmic steps of ASBAT optimization algorithm

The proposed ASBAT optimization algorithm is developed for the effective scheduling to accommodate traffic besides maintaining the QoS assurance. The prioritization of the data packets in the sensor node is done through the ASBAT optimization algorithm. The algorithmic steps involved in the optimization algorithm is as follows,

i) Initialization

The first step is the initialization of the solution. The position is randomly initialized as,

$$P = \{P_1, P_2, \ldots, P_m, \ldots P_n\}; 1 < m \leq n \tag{13}$$

where, the total number of solutions is represented as, n and the m^{th} solution is indicated as, P_m.

ii) Estimation of the fitness function

The fitness function is calculated to determine the best solution. The fitness function for the proposed ASBAT optimization algorithm is calculated in eqn. (10).

iii) Updation of the position

The performance of the algorithm is elevated as the ASO holds better self-adaptive convergence property that helps in the interaction of the atoms among each other. The position of the i^{th} atom at $(t+1)^{th}$ iteration is given as,

$$P_i(t+1) = P_i(t) + a_i(t+1) \tag{11}$$

where, position of the i^{th} atom at t^{th} iteration is given as, $P_i(t)$, the velocity of the i^{th} atom at $(t+1)^{th}$ iteration is denoted as, $a_i(t+1)$. The above equation is rearranged for evaluating $P_i(t)$, which is given as,

$$P_i(t+1) = P_i(t) + rand_i \, a_i(t) + q_i(t) \tag{12}$$

where, the acceleration of the i^{th} atom at t^{th} iteration is given as, $q_i(t)$ and the random number in [0, 1] is represented as, $Rand_i$. The velocity of the atom at $(t+1)^{th}$ iteration is updated using the bat algorithm. The bats fly at the position P with velocity a and fixed frequency of f. The bats can adjust the pulse emission and the wavelength rate automatically based on the proximity of their target. In the s-dimensional space, the velocity at the time t is calculated as,

$$a_i^{t+1} = a_i^t + \left(P_i^t - P^*\right) f_i \tag{13}$$

$$a_i^t = a_i^{t+1} - \left(P_i^t - P^*\right) f_i \tag{14}$$

Substituting the above eqn. in eqn. (12),

$$P_i(t+1) = P_i(t) + rand_i(a_i^{t+1} - (P_i^t - P^*) f_i) + q_i(t) \tag{15}$$

$$P_i(t+1) = P_i(t) + rand_i a_i(t+1) - rand_i P_i(t) f_i + rand_i P^* f_i + q_i(t) \tag{16}$$

$$P_i(t+1) = P_i(t)(1 - rand_i f_i) + rand_i(a_i(t+1) + P^* f_i) + q_i(t) \tag{17}$$

where, $f_i = f_{min} + (f_{max} - f_{min})\beta$, $\beta \in [0,1]$, P^* is the best solution, $f_{min} = 0$ and $f_{max} = 0(1)$

Thus, the eqn. (17) is the update position value of the proposed ASBAT optimization algorithm.

iv) Evaluation of the best solution

The fitness of the solution computed in the proposed ASBAT optimization algorithm is used for the evaluation of the best solution. The fitness function with the highest value is selected as the best solution for scheduling.

v) Termination

The end of the optimization process is the termination. The termination occurs at the end of the iteration. The pseudo code of the proposed ASBAT algorithm is depicted in Table 2.

Table 2:. Pseudo code of proposed ASBAT algorithm

```
Input:Solution set P, velocity a
Output: Pbest
Initialization of the atoms in random manner
  While stopping criteria is not reached do
    for each atom Pi, do
Evaluate the Fitness function using equation (10)
If Fi < Fbest, then
Fbest = Fa
Pbest = Pa
End if
Update the position using eqn (17)
End for
End while
Find the best solution so far Pbest
End
```

After priority scheduling, the assigned data slots are shared to the member nodes by B. The data slot allocation (DS_Alloc) message consists of member node ID along with the number of the data slot. It also sends the start time of the following control period to the member node that fails to sent the data request to the B. In order to avoid the contention, the member node determines and transmits the data slots as soon as receiving the DS_Alloc message. Thus, the data slot of smaller size reduced the duration of the time slot of the sensor node thus, improving the throughput of the network.

4.2.2. Inter-Cluster Communication

The data received from the member node is aggregated by B and transmitted to the BS using the CSMA technique. After a certain intervals of time, the next round begins and the procedure is repeated for following rounds. Fig.2 depicts the transmission of the control message among the B , BS and the member nodes in steady-state phase and setup phase.

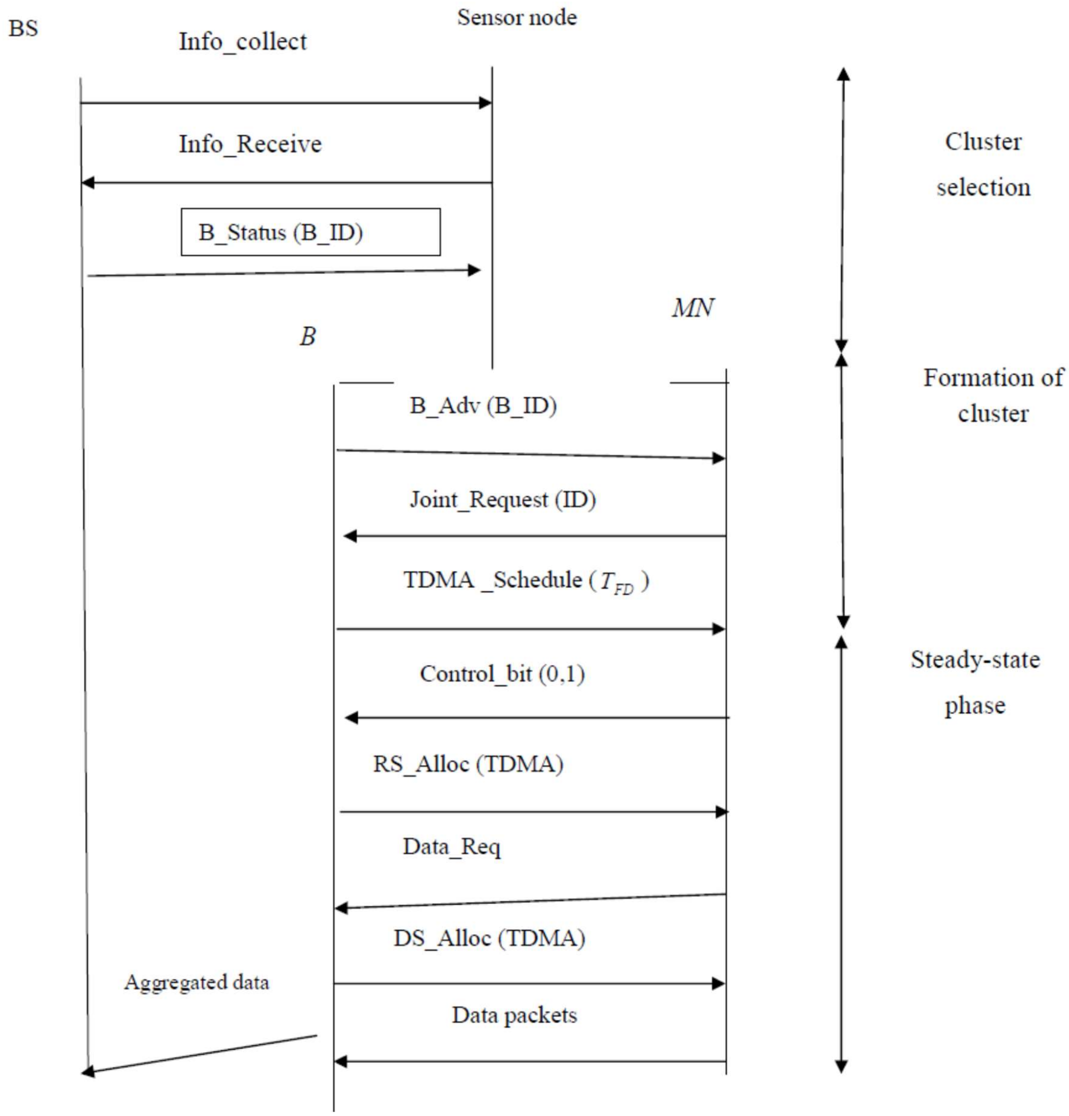

Fig.2. *Transmission of control message among BS,* B *and* MN

5. Result and Discussion

The section discusses the results of the proposed ASBAT-MAC protocol. The comparative anlaysis of the proposed ASBAT-MAC protocol is done using the performance metrics for 50, 100 and 150 nodes.

5.1 Experimental Setup

The proposed ASBAT-MAC protocol is implemented in MATLAB with Windows 10 Operating System and 2GB RAM.

5.1.1. Experimental Results

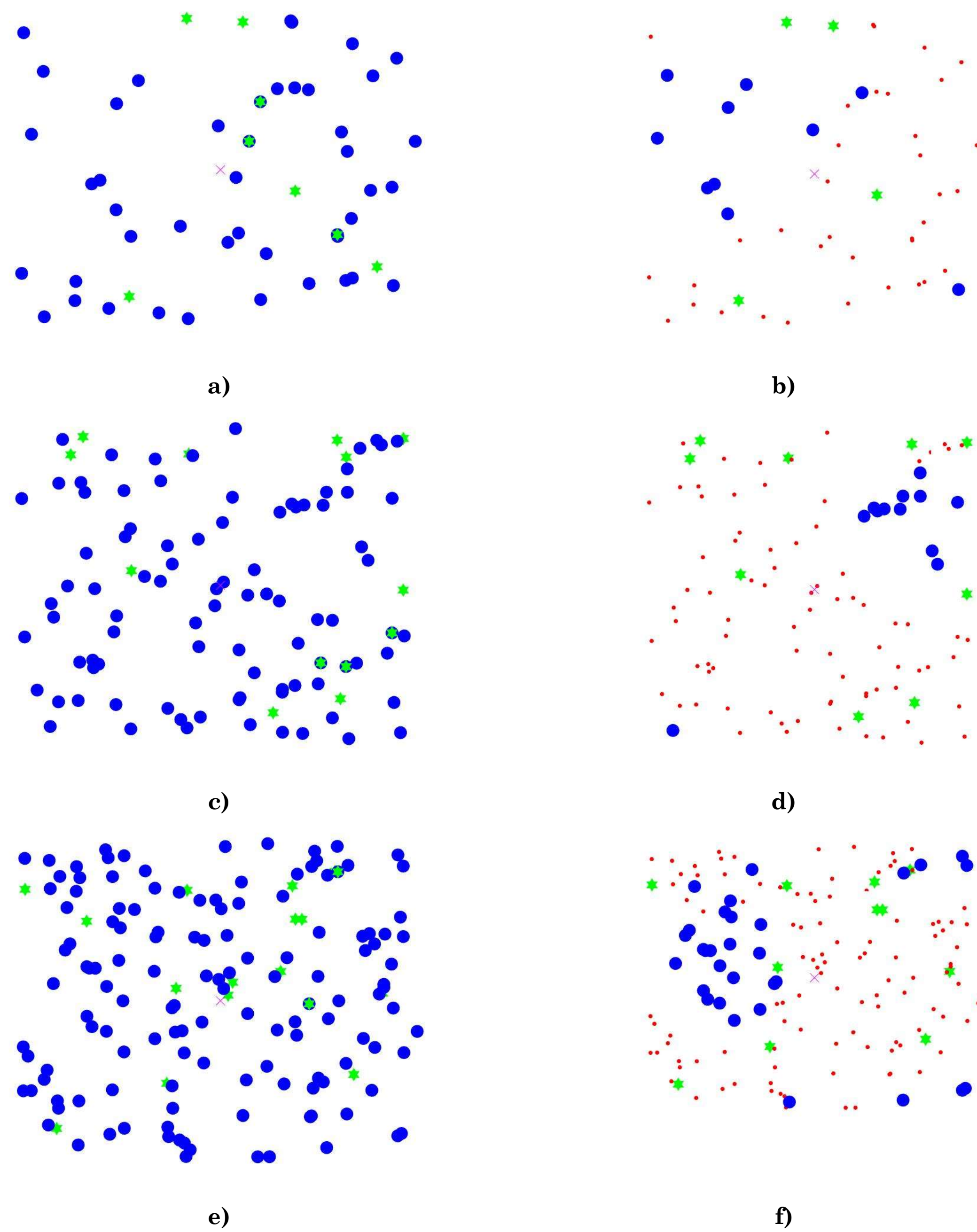

Fig.3. *Simulation results of a) round_0 for 50 nodes, b) round_1000 for 50 nodes, c) round_0 for 100 nodes, d) round_1000 for 100 nodes, e) round_0 for 150 nodes, f) round_1000 for 150 nodes*

This section describes the simulation results of proposed ASBAT-MAC for 50, 100 and 150 nodes. Fig. 3a) depicts the simulation results of the proposed ASBAT-MAC for 50 nodes at round_0. Fig. 3b) depicts the simulation results of the proposed ASBAT-MAC for 50 nodes at round_1000. Fig. 3 c) depicts the simulation results of the proposed ASBAT-MAC for 100 nodes at round_0. Fig. 3 d) depicts the simulation results of the proposed ASBAT-MAC for 100 nodes at round_1000. Fig. 3 e) depicts the simulation results of the proposed ASBAT-MAC for 150 nodes at round_0. Fig. 3 f) depicts the simulation results of the proposed ASBAT-MAC for 150 nodes at round_1000.

5.2. Simulation Parameters

Table 3 shows the simulation parameters of the proposed ASBAT-MAC protocol.

Table 3: Simulation Parameters

Type	Parameter	Value
Network	Number of nodes	50, 100, 150
Radio model	Number of CHs	5
	Energy	2J
	F_{elec}	10 nJ/bit
	F_{fs}	10 pJ/bit/ m^2
	F_{idle}	5 nJ/bit
	F_{DA}	5 nJ/bit/signal
Parameters of MAC Layer	Transmission bandwidth	24kbps
	Length of the Request slot	0.003 sec
	Length of the data slot	0.0083 sec
	Data traffic	180 Bytes to 2.85 KB

5.2.1 Performance Metrics

The performance metrics used for the analysis of the proposed ASBAT-MAC protocol are the number of alive nodes, Fairness, Normalized energy and Throughput.

- *Alive nodes:*
  Alive nodes are the nodes that initiate communication in the network.
- *Throughput:*
  The ratio of the number of packets of data obtained and delivered in a specific time is the throughput.

$$\text{Throughput} = {}^{N_p}\!/_{T}$$

where, the simulation time is given as, T and the number of nodes obtained is given as, N_p.

- *Energy:*
  The energy is the amount of energy consumed during the data transmission between the nodes.
- *Fairness:*
  Fairness denotes the distribution of the resources in a fair manner in the network.

5.3. Competing Methods

The competing methods, such as Energy Traffic Priority Scheduling-based QoS-aware MAC Protocol (ETPS-MAC) [1], ASO-MAC, Adaptive Hierarchical MAC Protocol (AH-MAC) [2], and Quorum time slot adaptive condensing (QTSAC) [3] are compared with the proposed ASBAT-MAC for proving the effectiveness of the proposed method.

5.4. Performance Metrics

The performance metrics used for the comparative analysis of the proposed ASBAT-MAC protocol are the number of alive nodes, Fairness, Normalized energy and Throughput.

5.4.1. Comparative Analysis Using 50 Nodes

Fig. 4 depicts the analysis of the proposed ASBAT-MAC protocol with the performance metrics for 50 nodes by varying the number of rounds. Fig. 4 a) comparative analysis of the proposed ASBAT-MAC protocol using alive nodes. At round 0, the alive nodes computed by the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC and the proposed ASBAT-MAC are 50. When the number of rounds is 1000, the alive modes of the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC protocol and the proposed ASBAT-MAC are 25, 26, 27, 27 and 28, respectively. At round 1500, the alive nodes computed by the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC and the proposed ASBAT-MAC are 5, 9, 12, 13 and 14, respectively. Fig. 4 b) comparative analysis of the proposed ASBAT-MAC protocol using fairness. When the number of rounds is 1000, the fairness of the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC protocol and the proposed ASBAT-MAC are 0, 0.0036, 0.2304, 0.25 and 0.2704, respectively. At round 500, the fairness obtained by the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC and the proposed ASBAT-MAC are 0.7396, 0.8464, 0.8836, 0.9216, and 0.9216, respectively.

Fig. 4 c) comparative analysis of the proposed ASBAT-MAC protocol using normalized energy. At round 500, the normalized energy obtained by the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC and the proposed ASBAT-MAC are 0.2872, 0.2977, 0.2979, 0.2997 and 0.3345, respectively. When the number of rounds is 1000, the normalized energy of the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC protocol and the proposed ASBAT-MAC are 0.0462, 0.0784, 0.0843, 0.0933 and 0.1187, respectively. Fig. 4 d) comparative analysis of the proposed ASBAT-MAC protocol using throughput. At round 500, the throughput obtained by the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC and the proposed ASBAT-MAC are 0.86, 0.92, 0.94, 0.96 and 0.96, respectively. When the number of rounds is 1000, the throughput of the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC protocol and the proposed ASBAT-MAC are 0, 0.06, 0.48, 0.5 and 0.52, respectively.

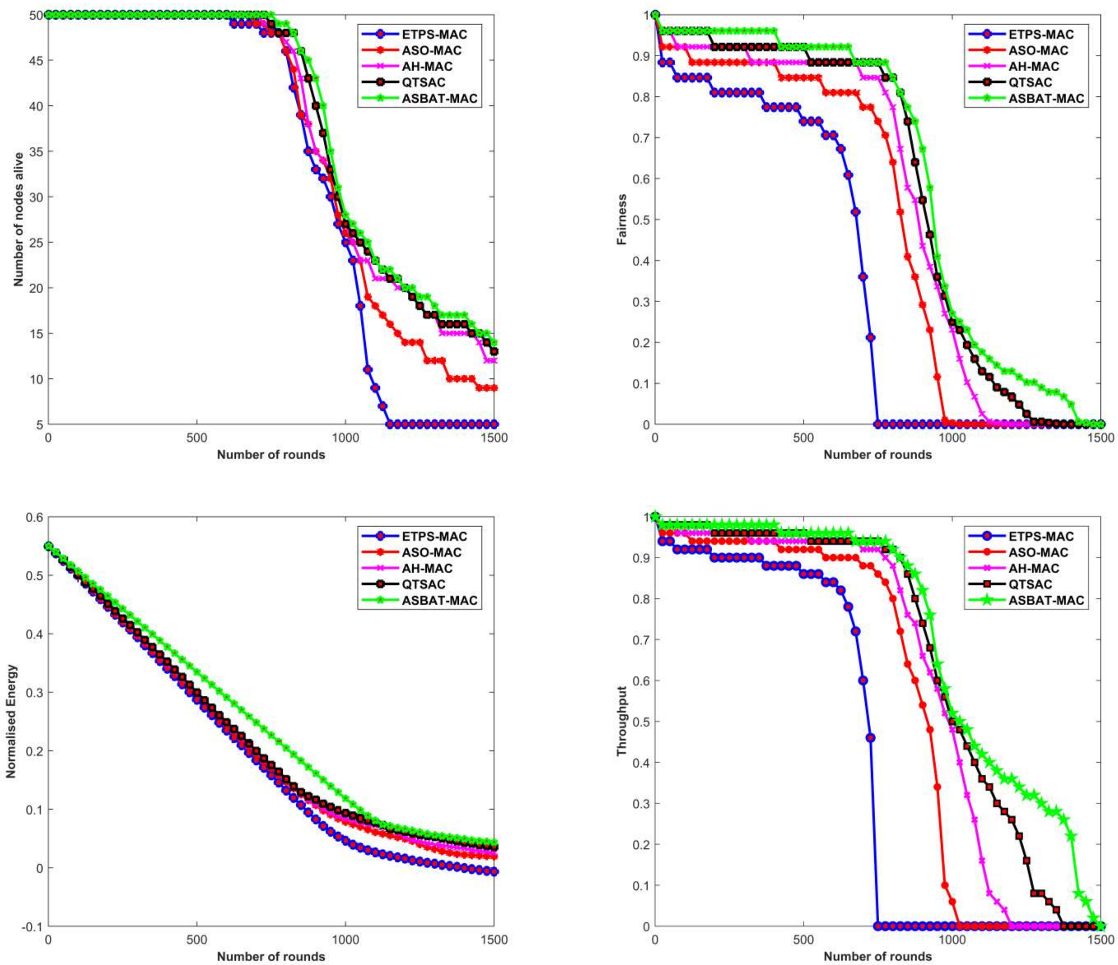

Fig.4. *Comparative analysis using 50 nodes, a) Number of alive nodes, b) Fairness, c) Normalized energy, d) Throughput*

5.4.2. Comparative Analysis Using 100 Nodes

Fig. 5 depicts the analysis of the proposed ASBAT-MAC protocol with the performance metrics for 100 nodes by varying the number of rounds. Fig. 5 a) comparative analysis of the proposed ASBAT-MAC protocol using alive nodes. At round 0, the alive nodes computed by the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC and the proposed ASBAT-MAC are 100. When the number of rounds is 1000, the alive modes of the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC protocol and the proposed ASBAT-MAC are 50, 52, 52, 54 and 54, respectively. At round 1500, the alive nodes computed by the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC and the proposed ASBAT-MAC are 8, 21, 22, 23 and 23, respectively. Fig. 5 b) comparative analysis of the proposed ASBAT-MAC protocol using fairness. At round 500, the fairness obtained by the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC and the proposed ASBAT-

MAC are 0.7921, 0.9025, 0.9409, 0.9409 and 0.9409, respectively. When the number of rounds is 1000, the fairness of the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC protocol and the proposed ASBAT-MAC are 0, 0.1156, 0.2304, 0.2601 and 0.2704, respectively.

Fig. 5 c) comparative analysis of the proposed ASBAT-MAC protocol using normalized energy. At round 500, the normalized energy obtained by the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC and the proposed ASBAT-MAC are 0.2867, 0.2873, 0.2888, 0.2908 and 0.3392, respectively. When the number of rounds is 1000, the normalized energy of the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC protocol and the proposed ASBAT-MAC are 0.0620, 0.0759, 0.0791, 0.0798 and 0.1284, respectively. Fig. 5 d) comparative analysis of the proposed ASBAT-MAC protocol using throughput. At round 500, the throughput obtained by the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC and the proposed ASBAT-MAC are 0.89, 0.95, 0.97, 0.97 and 0.97, respectively. When the number of rounds is 1000, the throughput of the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC protocol and the proposed ASBAT-MAC are 0, 0.34, 0.48, 0.51, and 0.52, respectively.

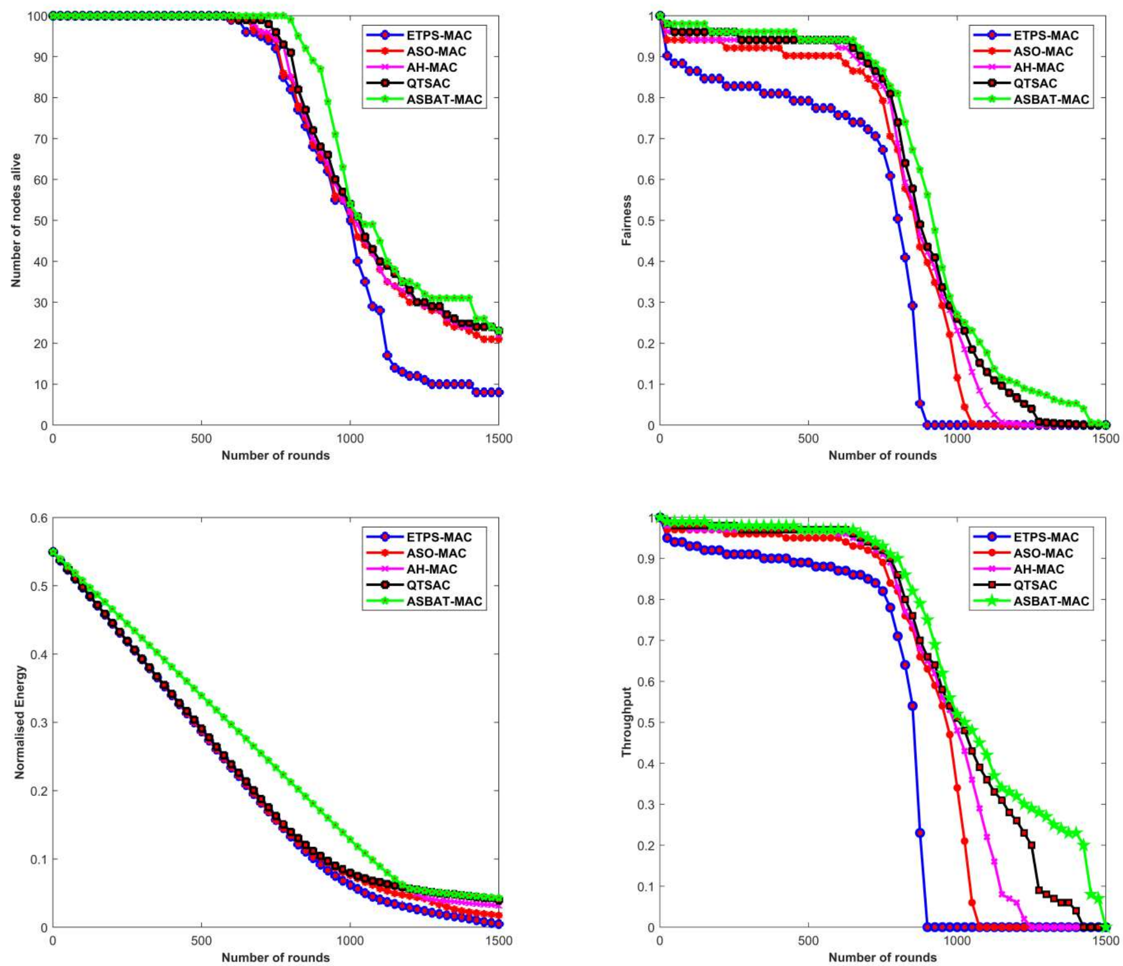

Fig.5. *Comparative analysis using 100 nodes, a) Number of alive nodes, b) Fairness, c) Normalized energy, d) Throughput*

5.4.3. Comparative Analysis using 150 Nodes

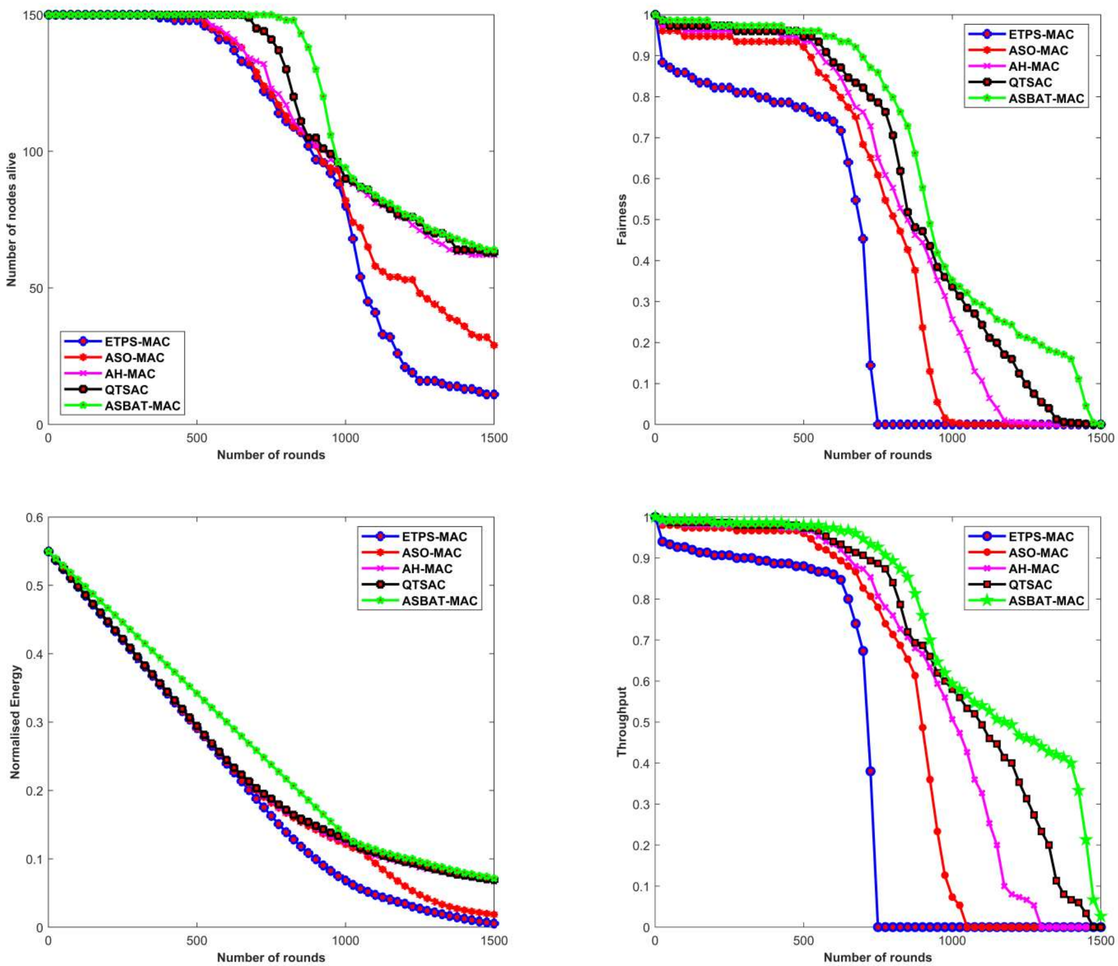

Fig.6.*Comparative analysis using 150 nodes, a) Number of alive nodes, b) Fairness, c) Normalized energy, d) Throughput*

Fig.6 depicts the analysis of the proposed ASBAT-MAC protocol with the performance metrics for 150 nodes by varying the number of rounds. Fig.6 a) comparative analysis of the proposed ASBAT-MAC protocol using alive nodes. At round 0, the alive nodes computed by the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC and the proposed ASBAT-MAC are 150. When the number of rounds is 1000, the alive modes of the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC protocol and the proposed ASBAT-MAC are 80, 82, 90, 90, 94, respectively. At round 1500, the alive nodes computed by the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC and the proposed ASBAT-MAC are 11, 29, 62, 63, 64, respectively. Fig.6 b) comparative analysis of the proposed ASBAT-MAC protocol using fairness. When the number of rounds is 500, the fairness of the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC protocol and the proposed ASBAT-MAC are 0.7744, 0.9216, 0.9344, 0.9474, and 0.9604, respectively. At round 1000, the fairness obtained by the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC and the proposed ASBAT-MAC are 0, 0.0054, 0.2567, 0.3364, and 0.3520, respectively.

Fig.6 c) comparative analysis of the proposed ASBAT-MAC protocol using normalized energy. At round 500, the normalized energy obtained by the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC and the proposed ASBAT-MAC are 0.2911, 0.2913, 0.2928, 0.2943 and 0.3420, respectively. When the number of rounds is 1000, the normalized energy of the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC protocol and the proposed ASBAT-MAC are 0.0684, 0.1215, 0.1242, 0.1297, and 0.1339, respectively. Fig.6 d) comparative analysis of the proposed ASBAT-MAC protocol using throughput. At round 500, the throughput obtained by the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC and the proposed ASBAT-MAC are 0.8800, 0.9600, 0.9667, 0.9733 and 0.9800, respectively. When the number of rounds is 1000, the throughput of the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC protocol and the proposed ASBAT-MAC are 0, 0.0733, 0.5067, 0.5800, 0.5933, respectively.

5.5. Comparative Discussion

This section describes the comparative discussion of the proposed ASBAT-MAC along with the existing method using the performance metrics for 50, 100 and 150 nodes.

Table 4: Comparative discussion of the protocol using 50 nodes

Metrics	ETPS-MAC	ASO-MAC	AH-MAC	QTSAC	proposed ASBAT-MAC
alive nodes	25	26	27	27	**28**
fairness	0	0.0036	0.2304	0.25	**0.2704**
normalized energy	0.0462	0.0784	0.0843	0.0933	**0.1187**
throughput	0	0.06	0.48	0.5	**0.52**

Table 4 shows the comparative discussion of the proposed ASBAT-MAC along with the existing method using the performance metrics for 50 nodes. When the number of rounds is 1000, the alive modes of the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC protocol and the proposed ASBAT-MAC are 25, 26, 27, 27 and 28, respectively. When the number of rounds is 1000, the fairness of the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC protocol and the proposed ASBAT-MAC are 0, 0.0036, 0.2304, 0.25 and 0.2704, respectively. When the number of rounds is 1000, the normalized energy of the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC protocol and the proposed ASBAT-MAC are 0.0462, 0.0784, 0.0843, 0.0933 and 0.1187, respectively. When the number of rounds is 1000, the throughput of the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC protocol and the proposed ASBAT-MAC are 0, 0.06, 0.48, 0.5 and 0.52, respectively.

Table 5: Comparative discussion of the protocol using 100 nodes

Metrics	**ETPS-MAC**	**ASO-MAC**	**AH-MAC**	**QTSAC**	proposed ASBAT-MAC
alive nodes	50	52	52	54	**54**
fairness	0	0.1156	0.2304	0.2601	**0.2704**
normalized energy	0.0620	0.0759	0.0791	0.0798	**0.1284**
throughput	0	0.34	0.48	0.51	**0.52**

Table 5 shows the comparative discussion of the proposed ASBAT-MAC along with the existing method using the performance metrics for 100 nodes. When the number of rounds is 1000, the alive modes of the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC protocol and the proposed ASBAT-MAC are 50, 52, 52, 54 and 54, respectively. When the number of rounds is 1000, the fairness of the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC protocol and the proposed ASBAT-MAC are 0, 0.1156, 0.2304, 0.2601 and 0.2704, respectively.When the number of rounds is 1000, the normalized energy of the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC protocol and the proposed ASBAT-MAC are 0.0620, 0.0759, 0.0791, 0.0798 and 0.1284, respectively. When the number of rounds is 1000, the throughput of the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC protocol and the proposed ASBAT-MAC are 0, 0.34, 0.48, 0.51, and 0.52, respectively.

Table 6: Comparative discussion of the protocol using 150 nodes

Metrics	**ETPS-MAC**	**ASO-MAC**	**AH-MAC**	**QTSAC**	proposed ASBAT-MAC
alive nodes	80	82	90	90	**94**
fairness	0	0.0054	0.2567	0.3364	**0.3520**
normalized energy	0.0684	0.1215	0.1242	0.1297	**0.1339**
throughput	0	0.0733	0.5067	0.5800	**0.5933**

Table 6 shows the comparative discussion of the proposed ASBAT-MAC along with the existing method using the performance metrics for 150 nodes. When the number of rounds is 1000, the alive modes of the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC protocol and the proposed ASBAT-MAC are 80, 82, 90, 90, 94, respectively. At round 1000, the fairness obtained by the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC and the proposed ASBAT-MAC are 0, 0.0054, 0.2567, 0.3364, and 0.3520, respectively. When the number of rounds is 1000, the normalized energy of the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC protocol and the proposed ASBAT-MAC are 0.0684, 0.1215, 0.1242, 0.1297, and 0.1339, respectively. When the number of rounds is 1000, the throughput of the existing ETPS-MAC, ASO-MAC, AH-MAC, QTSAC protocol and the proposed ASBAT-MAC are 0, 0.0733, 0.5067, 0.5800, and 0.5933, respectively.

6. Conclusion

This paper proposes a scheduling based MAC protocol for delay sensitive WSN. The proposed ASBAT-MAC scheduling algorithm is developed by integrating the ASO algorithm and the BAT algorithm. The scheduling algorithm balanced the consumption of energy in WSN and reduced the interfering node collision. Based on the delay, fairness and the residual energy, the data packets of the sensor nodes are prioritized. The nodes with short inter-BS distance and higher residual energy is selected as the CH in the rank-based clustering approach for prolonging the network lifetime. The developed MAC protocol helps in coordinating the access of the nodes to the shared wireless medium for maximizing the throughput and reducing the collisions significantly. The simulation of the proposed ASBAT-MAC protocol is based on the performance metrics, like number of alive nodes, Fairness, Normalized energy and Throughput for nodes 50, 100 and 150 by varying the number of rounds. When compared to the existing protocols, the proposed ASBAT-MAC protocol obtained a maximum number of alive nodes of 94, maximum fairness of 0.3520, maximum normalized energy of 0.1339 and maximum throughput of 0.5933, respectively for 150 nodes. The future enhancement can be done by implementing hybrid optimization algorithm for scheduling.

Compliance with Ethical Standards

Conflicts of interest: Authors declared that they have no conflict of interest.

Human participants: The conducted research follows ethical standards and the authors ensured that they have not conducted any studies with human participants or animals.

References

[1] Kaur, T. and Kumar, D., "ETPS-MAC: Energy Traffic Priority Scheduling-based QoS-aware MAC protocol for hierarchical WSNs", International Journal of Electronics, vol. 106, no. 9, pp.1344-1359, 2019.

[2] Al-Sulaifanie, A.I., Biswas, S. and Khorsheed Al-Sulaifanie, B., "AH-MAC: adaptive hierarchical MAC protocol for low-rate wireless sensor network applications", Journal of Sensors, 2017.

[3] Liu, Y., Ota, K., Zhang, K., Ma, M., Xiong, N., Liu, A. and Long, J., "QTSAC: An energy-efficient MAC protocol for delay minimization in wireless sensor networks", IEEE Access, 6, pp.8273-8291, 2018.

[4] Swain, R.R., Mishra, S., Samal, T.K. and Kabat, M.R., "An energy efficient advertisement based multichannel distributed MAC protocol for wireless sensor networks (Adv-MMAC)", Wireless Personal Communications, vol. 95, no. 2, pp.655-682, 2017.

[5] Singh, R., Rai, B.K. and Bose, S.K., "A joint routing and MAC protocol for transmission delay reduction in many-to-one communication paradigm for wireless sensor networks", IEEE Internet of Things Journal, vol. 4, no. 4, pp.1031-1045, 2017.

[6] Movva, P. and Rao, P.T., "Novel Two-Fold Data Aggregation and MAC Scheduling to Support Energy Efficient Routing in Wireless Sensor Network", IEEE Access, vol. 7, pp.1260-1274, 2018.

[7] Siddiqui, S., Ghani, S. and Khan, A.A., "ADP-MAC: An adaptive and dynamic polling-based MAC protocol for wireless sensor networks", IEEE Sensors Journal, vol. 18, no. 2, pp.860-874, 2017.

[8] Kang, M.W. and Chung, Y.W., "A novel energy-aware routing protocol in intermittently connected delay-tolerant wireless sensor networks", International Journal of Distributed Sensor Networks, vol. 13, no. 7, 2017.

[9] Chen, Y., Shu, J., Zhang, S., Liu, L. and Sun, L., "Data fusion in wireless sensor networks", IEEE Second International Symposium on Electronic Commerce and Security, Vol. 2, pp. 504-509, May 2009.

[10] K. Ramanan and E. Baburaj, "Data gathering algorithms for wireless sensor networks: a survey," International Journal of Ad Hoc, Sensor & Ubiquitous Computing, vol. 1, no. 4, pp. 102–114, 2010.

[11] M. Minami, T. Morito, H. Morikawa, and T. Aoyama, "Solar biscuit: a batteryless wireless sensor network system for environmental monitoring applications," in Proceedings of the 2nd International Workshop on Networked Sensing Systems, San Diego, Calif, USA, 2005.

[12] Sudevalayam, S. and Kulkarni, P., "Energy harvesting sensor nodes: Survey and implications", IEEE Communications Surveys & Tutorials, vol. 13, no. 3, pp.443-461, 2010.

[13] Halil Yetgin, Kent Tsz Kan Cheung, Mohammed El-Hajjar, and Lajos Hanzo, "A Survey of Network Lifetime Maximization Techniques in Wireless Sensor Networks", IEEE Communications Surveys and Tutorials, Vol. 19, no. 2, pp 828-854, 2017.

[14] Omer Cayirpunar, Esra Kadioglu-Urtis, and Bulent Tavli, "Optimal Base Station Mobility Patterns for Wireless Sensor Network Lifetime Maximization", IEEE Sensors Journal, vol. 15, no. 11, pp 6592-6603, 2017.

[15] Yang, X.S., "A new metaheuristic bat-inspired algorithm", In Nature inspired cooperative strategies for optimization (NICSO 2010), Springer, Berlin, Heidelberg, pp. 65-74, 2010.

[16] Zhao W., Wang L. and Zhang Z, "Atom search optimization and its application to solve a hydrogeologic parameter estimation problem", Knowledge-Based Systems, vol. 163, pp.283-304, 2019.

[17] Dini, G. and Duca, A.L., "Towards a reputation-based routing protocol to contrast blackholes in a delay tolerant network," Ad Hoc Networks, vol.10, no.7, pp.1167-1178, 2012.

[18] Kumar, R. and Kumar, D., "Multi-objective fractional artificial bee colony algorithm to energy aware routing protocol in wireless sensor network," Wireless Networks, vol.22, no.5, pp.1461-1474, 2016.

[19] Ahmed, I., Mohamed, A., Fouly, T. and Hu, Y.C., 2011, February. On the fairness of frequency domain resource allocation in Wireless Mesh Networks—A survey. In 2011 IEEE GCC Conference and Exhibition (GCC) (pp. 517-520). IEEE.

[20] A. Krifa, C. Baraka, T. Spyropoulos, Optimal buffer management policies for delay tolerant networks, in: Sensor, Mesh and Ad Hoc Communications and Networks (SECON 2008), San Francisco, CA, pp. 260–268, 2008,

[21] S.Q. Ali, A. Junaid Baig, Routing protocols in delay tolerant networks – a survey, in: International Conference on Emerging Technologies (ICET 2010), Islamabad, Pakistan, pp. 70–75, 2010.

[22] M. Musolesi, C. Mascolo, "Car: context-aware adaptive routing for delay-tolerant mobile networks," IEEE Transactions on Mobile Computing, vol.8, 246–260, 2009.

[23] Chu, Y., Mitchell, P., Grace, D., Roberts, J., White, D. and Mickus, T., "IRIS: A Low Duty Cycle Cross-Layer Protocol for Long-Range Wireless Sensor Networks with Low Power Budget", Computer Networks, pp.109666, 2023.

[24] Zeng, Z., He, B., Liu, A., Zhang, S. and Xiong, N.N., "PA-WuRES: A green pre-awake routing protocol for wake-up radio enable sensor networks", Alexandria Engineering Journal, Vol. 68, pp.633-646, 2023.

[25] Kalaivanan, K., Idayachandran, G., Vetrivelan, P., Henridass, A., Bhanumathi, V., Chang, E. and Methuselah, P.S., "An Energy-Efficient T-Based Routing Topology for Target Tracking in Battery Operated Mobile Wireless Sensor Networks. Sensors", Vol. 23(4), pp.2162, 2023.

[26] Dev, J. and Mishra, J., "Energy-Efficient Object Detection and Tracking Framework for Wireless Sensor Network", Sensors, Vol. 23(2), pp.746, 2023.

[27] Zheng, A., Zhang, Z., Liu, W., Liu, J., Xiao, Y. and Li, C., "Dual Cluster Head Optimization of Wireless Sensor Networks Based on Multi-Objective Particle Swarm Optimization", Sensors, Vol. 23(1), pp.231, 2023.

[28] Weber, M., Fersi, G., Fromm, R. and Derbel, F., "Wake-Up Receiver-Based Routing for Clustered Multihop Wireless Sensor Networks', Sensors, Vol. 22(9), pp.3254, 2022.

[29] Dogra, R., Rani, S., Babbar, H. and Krah, D., "Energy-efficient routing protocol for next-generation application in the internet of things and wireless sensor networks", Wireless Communications and Mobile Computing, 2022.

[30] Kaur, P., Kaur, K., Singh, K. and Kim, S., "Early Forest Fire Detection Using a Protocol for Energy-Efficient Clustering with Weighted-Based Optimization in Wireless Sensor Networks", Applied Sciences, Vol. 13(5), pp.3048, 2023.