Abstract—The transmission time, data delivery reliability and network lifetime are three fundamental but conflicting design objectives in energy-constrained Wireless Sensor Networks (WSNs). In this paper, address the optimal reliability constraint -lifetime tradeoff with source-to-sink transport delay, and energy constraint (network lifetime). By introducing the optimization function, we combine the objectives into a single objective to characterize the tradeoff among them. This work proposed a new Enhanced Artificial Bee Colony Algorithm, i.e. EABC, which combines Differential Evolution (DE) with gbest-guided ABC (GABC) by an evaluation strategy with an attempt to utilize more prior information of the previous search experience to speed up the convergence. In addition, to improve the global convergence, when producing the initial population, a chaotic opposition-based population initialization method is employed. In addition, this work also introduces a new data gathering protocol named Broadcasting Combined with Multi-NACK/ACK (BCMN/A) protocol based on the analysis strategy. The BCMN/A protocol achieve energy and delay efficiency during the data gathering process both in intra-cluster and inter-cluster. The energy for data gathering in intra-cluster is preserved and transport delay is decreased with multi-NACK and EABC mechanism. Finally, conduct an extensive simulation experiments using Network Simulator (NS2). Consistently with the theoretical results, simulation results demonstrate that the BCMN/A with EABC protocol is efficiency in both energy and delay under network reliability constraint, which on average improves the network lifetime.

Keywords—Broadcasting Combined with Multi-NACK/ACK; Differential Evolution with Gbest-guided ABC; Energy Efficient; Network Lifetime; Network Simulator; Wireless Sensor Networks.

Abbreviations—Broadcasting Combined with Multi-NACK/ACK (BCMN/A); Carrier Sensing Multiple Access (CSMA); Differential Evolution (DE) with Gbest-guided ABC (GABC); Enhanced Artificial Bee Colony Algorithm (EABC); Network Simulator (NS2); Wireless Sensor Networks (WSNs).

I. INTRODUCTION

WIRELESS SENSOR NETWORKs (WSNs) are commonly used for environmental monitoring, surveillance operations, and home or industrial automation [Albath et al., 1; Jin et al., 2; Cheng et al., 3; Liu et al., 4]. In cluster based WSNs, the Cluster Head (CH) performs aggregation of all received data from its cluster members and then forwards it to the sink in a multi-hop manner. Due to the unreliability of WSNs, it results in large energy consumption for multiple retransmissions and gains unexpected network performance [Liu et al., 4; Rosberg et al., 5]. For example, since the packet loss for the communication among nodes is up to 30%, the success rate becomes only 16.8% after five hops to the sink. Thus, the reliability achieves 90% only if at least two retransmissions have been done in each hop. In other words, network energy is supposed to be consumed twice more than expected at each hop. Thus, it is necessary to design a new protocol to guarantee QoS in WSNs such as lifetime, end-to-end reliability, and delay. Send and Wait Automatic Repeatre Quest (ARQ) protocol (SW-ARQ) is commonly used to
ensure the reliability by employing multiple retransmissions [Rosberg et al., 5].

For the QoS of wireless sensor applications, energy efficiency [Pu et al., 6; Xu et al., 7] and delay [Kim et al., 8] are two of the most significant indicators. Since wireless sensor nodes are battery-powered, their energy is limited. Thus, improving energy efficiency [Xie et al., 9] is an important research area for WSNs. There are many studies regarding energy efficiency, which include optimization in a single layer and joint optimization in multiple layers. For instance, optimization methods in the MAC layer [Teng et al., 10], network layer and application layer, and cross-layer optimization methods have been proposed. Methods that address the MAC layer include adjusting the transmission power of the nodes [Teng et al., 10], selecting optimized MAC parameters [Teng et al., 10], and the dynamic duty cycle [Teng et al., 10]. The network routing optimization method in the network layer and selecting the optimal size of data packets in the application layer [Teng et al., 10] are effective methods, as well.

Due to the complexity of cluster based networks, there is little research efforts in achieving all of network reliability, transport delay, and lifetime optimization. Novel Enhanced Artificial Bee Colony Algorithm (EABC) is introduced that integrates Differential Evolution (DE) with gbest-guided ABC (GABC) by means of an analysis strategy trying to use more early information on the prior search experience for speeding up the convergence. Also, in order to enhance the global convergence, while generating the initial population, a chaotic opposition-based population initialization technique is used. The energy for data collecting in intra-cluster is saved and transport delay is reduced with multi-NACK strategy. At the same time, in inter-clusters, multi-ACK is sent back each and every time a sensor node transmits any data packet. A protocol, identically, the node transport delay consists of the delay of data collection within the cluster and the delay of data transmitted to the sink.

II. Literature Review

Xu et al., [11] addressed the tradeoff concerned with optimal rate-reliability-lifetime and constraints associated with link capacity, reliability and energy. By a sequence of transformations, a dissociable and convex problem is obtained, and an effective distributed Sub gradient Dual Decomposition algorithm (SDD) is introduced. Numerical examples ensure its convergence. In addition, numerical examples examine the effect of weight parameters on the utilities of rate, reliability and network lifespan that renders a guidance to correctly fix the value of weight parameters for a satisfying performance of WSNs based on the requirements of the practical application.

Kwon et al., [12] examined the issue of the lifetime increase in a wireless sensor network under the limitation of the probability target end-to-end transmission success, by following a cross-layer mechanism, which takes both physical layer (i.e., power control) and network layer (i.e., routing protocol) together into consideration. First, the optimal power allocation algorithm is presented for a routing path given. Then, an optimal routing algorithm is developed, which increases the network lifespan and a heuristic algorithm, which has lesser and manageable complexity. The results obtained from simulation indicate that a compromising relationship exists between the maximization of the network lifetime and the reliability constraint, and the newly introduced routing algorithm integrated with the optimal power allocation algorithm maximizes the network lifespan in a significant manner.

Wan et al., [13] suggested the design, realization, and assessment of pump in a slowly, fetch quickly (PSFQ), which is a simple, scalable, and reliable transport protocol that can be personalized to satisfy the requirements of the developing trust worthy data applications in sensor networks. PSFQ indicates an easy mechanism as it assumes minimally regarding the routing infrastructure beneath, and offers scalability and energy-efficiency with minimal signaling, thus decreasing the communication expense for data reliability, and more significantly. Results indicate that PSFQ can perform better than the available methodologies related and are hugely sensitive to the different error scenarios faced in sensor networks. The source code for PSFQ is available freely for experimentation purposes.

Akan & Akyildiz [14] exploited the fact that the redundancy observed in sensed data aggregated in thick WSNs can carry out the mitigation of channel error and node failure, the sink adaptively accomplishes the anticipated event reliability by regulating the reporting frequency of the source nodes. A novel reliable transport mechanism is proposed for WSN, the Event-To-Sink Reliable Transport (ESRT) protocol. This self-organizing characteristic of ESRT renders it strong to a stochastic, dynamic topology in WSN. Moreover, ESRT can also deal with several consecutive occurrences of event in a wireless sensor field. The performance evaluation carried out analytically and the results from simulation indicate that ESRT converges to the required reliability with minimal energy usage, beginning with any initial state of the network.

Deb et al., [15] explained a protocol known as Re lnForM for delivering the packets at needed reliability at a proportional communication expense. ReIn ForM uses this characteristic in its randomized forwarding technique that leads to using every possible path and effective load balancing. Apparently, the data transmission rate and the data delivery reliability are two basic, yet contradictory, design goals in WSNs. An inherent compromise exists between them. But, all these above mentioned works did not take the inherent problem of rate-reliability tradeoff into consideration.

The current work [Lee et al., 16] has first explored the rate-reliability tradeoff problem in an explicit manner. By means of the extended NUM framework, where the user utility is dependent on both the transmission rate and reliability of delivery, the optimal rate-reliability tradeoff can be regulated by using the channel code rate in every link’s
physical-layer error correction codes. But, it did not consider the energy constraint, one of the most essential limitations in WSNs. Generally, sensor nodes are battery-driven, and replacement of battery is not possible in several sensing applications.

Liu et al., [17] developed a near optimal joint routing- and sleep scheduling technique for maximizing the network lifespan. Attempts for addressing the deficit of a joint routing-and-sleep-scheduling mechanism are studied in the literature by including the design of the two elements into one optimization framework. As it is observed, joint routing-and-sleep-scheduling by itself is a problem of non-convex optimization, which is hard to be solved. The problem is tackled by changing it into an equivalent Signomial Program (SP) by imposing a relaxation on the flow conservation limitations. Then the SP problem is resolved by means of an iterative Geometric Programming (IGP) technique, rendering a close to optimal routing-and-sleep-scheduling approach, which increase the network lifespan. As far as the best of knowledge goes, this is regarded as the first effort to get the optimal joint routing-and-sleep-scheduling mechanism for wireless sensor networks. The close to optimal solution rendered by this technical work paves new ways for the design of real-life and heuristic mechanisms that target the same problem, at present, the performance of any novel heuristics can be simply assessed by making use of the newly introduced near optimal scheme in the form of a standard.

Cheng et al., [18] addressed the joint routing and link rate allocation under bandwidth and energy constraints for prolonging the network lifespan and to enhance the throughput. The adequate condition on link bandwidth are discussed, which makes a routing solution to be practical, then mathematical optimization models are provided to deal with both energy and bandwidth constraints. The results obtained from simulation indicate that these heuristics yield more practical routing solutions compared to earlier work, and offers considerable increase on throughput and lifespan.

Ehsan et al., [19] introduced the energy and cross-layer aware routing mechanism for multichannel access WSNs, which take radio, MAC contention, and network constraints into consideration, targeting at the maximization of the network lifespan. Cross-layer methods applicable for WSNs are developed, which have the capacity of multichannel access. At last, elaborate simulation studies are performed in order to assess and then compare the performance of the newly introduced routing techniques under different network conditions.

Abdulla et al., [20] studied HYbrid Multi-hop routiNg (HYMN) algorithm, a mix of the flat multi-hop routing and hierarchical multihop routing, for sufficient prolonging of the lifespan of critically resource-limited sensor nodes. This uses effective transmission distances, and hierarchical multi-hop routing algorithms, which exploit data aggregation. After this, thorough mathematical analysis for HYMN is provided for optimizing it and modelling its power usage. Moreover, by means of elaborate simulations, the overall performance of HYMN is demonstrated in terms of superior connectivity.

III. PROPOSED METHODOLOGY

Novel Enhanced Artificial Bee Colony Algorithm (EABC) is introduced that integrates Differential Evolution (DE) with gbest-guided ABC (GABC) by means of an analysis strategy trying to use more early information on the prior search experience for speeding up the convergence. Also, in order to enhance the global convergence, while generating the initial population, a chaotic opposition-based population initialization technique is used. The energy for data collecting in intra-cluster is saved and transport delay is reduced with multi-NACK strategy. At the same time, in inter-clusters, multi-ACK is sent back each and every time a sensor node transmits any data packet. A protocol, identically, the node transport delay consists of the delay of data collection within the cluster and the delay of data transmitted to the sink. Employ a network model used in [Xu et al., 21], which is described as follows. Figure 1 shows data transmission of the network.

![Figure 1: The Data Transmission in Cluster based Networks](image)

3.1. Network Model

It consists of the following properties

1) ‘n’ homogenous sensor nodes are deployed in a circular region with a sink situated at the centre. The node distribution follows a homogenous Poisson point process with a density of r nodes per unit area.

The nodes in the network are divided into multiple clusters, each comprising a CH and cluster members that communicate via one hop to the CH. Data of CH is sent to the sink via multi-hop among CHs.

2) The transmitting radius of a node is denoted with R, and the cluster radius R is denoted with r. The transmission power of the node is adjustable, i.e. the node can adjust its transmission power according to the distance to a receiver, e.g., Berkeley Mote has 100 transmission power levels [Song et al., 22].

3) For every node i, the probability that data transmission from node i to node i + 1 is de noded by 1 - p_i (denoted with \( \tilde{p}_i \)) [Karaboga & Akay, 33]. The probability that node i successfully receives acknowledgment or negative acknowledgment (ACK/NACK) from node i+1 is denoted by 1 - q_i (denoted with \( \tilde{q}_i \)) [Rosberg et al., 23]. Assume
that reception failures are spatial dependent but time independent.

4) Deploying SW-HBH ARQ protocol [Rosberg et al., 23], nodes within a cluster send data to their CH with TDMA mechanism, and the data reliability within the cluster is $\delta_1$. Data is transmitted with pre-assigned different frequencies inter-clusters so that the data gathering inter-clusters can work simultaneously [Ota et al., 24]. The CHs send data to the sink hop by hop with Carrier Sensing Multiple Access (CSMA) mechanism and the reliability is $\delta_2$.

5) Time is slotted and the slot time is fixed as $D_s$ seconds corresponding to a single packet transmission. The transmitter serves new arrival packets on a first come first serve (FCFS) basis.

3.2. Energy Consumption Model and Related Definitions

In this work use the topical energy consumption model in [Kamal & Hamid, 25], where the transmission energy consumption $E_t$ follows eq. (1) and energy consumption $E_r$ for receiving follows eq. (2):

$$ E_t = \begin{cases} E_{elec} + \rho \cdot d^2 & \text{if } d < d_0 \\ E_{elec} + \rho \cdot d^4 & \text{if } d > d_0 \end{cases} \quad (1) $$

$$ E_r = \frac{E_{elec}}{\text{ transmit }} \quad (2) $$

$E_{elec}$ represents transmitting circuit loss. Both the free space ($d^2$ power loss) and the multi-path fading ($d^4$ power loss) channel models are used in the model, depending on the distance between the transmitter and receiver. $\rho$ and $\rho_{trans}$ are respectively the energy required by power amplification in the two models. ‘l’ represents the bits of data sent or received by nodes. The above parameter settings are adopted from Ref. [Naeimi et al., 26].

3.3. Problem Statement

Definition 1 (Transport delay)

The transport delay is defined as the time from a packet’s first transmission until its successful arrival at the sink [Han & Lee, 27].

Definition 2 (Network lifetime)

The network lifetime is defined as the time when first node dies [Liu et al., 28], In this work, the main problems are:

(1) In cluster based sensor networks, give the node energy consumption (network lifetime) and transport delay under reliability constraint from theoretical analysis;

(2) How to further decrease the network delay and improve the network lifetime under the data reliability.

3.4. Delay and Lifetime Analysis under SW HBH ARQ Protocol

In this section, present an analysis strategy to meet requirements of the application through trade-offs between the energy consumption and source-to-sink transport delay under SW HBH ARQ protocol for cluster based WSNs.

3.4.1. Analysis of Node Data Load under SW HBH ARQ Protocol

SW HBH ARQ is a data reliability protection protocol, its data gathering process is as the following:

1) Data gathering within the cluster, nodes within the cluster send data to the CH directly. If a transmitter receives an ACK from CH node before the preset timeout occurs, it transmits a new packet; otherwise, it retransmits the preceding packet. CH transmits an ACK for every packet it receives successfully including for duplicates;

2) Data inter-cluster heads is sent to the sink via multi-hop of CHs. The data reliability is assured in every hop.

If a transmitter receives an ACK from its subsequent CH node before the preset timeout occurs, it transmits a new packet; otherwise, it retransmits the preceding packet. A receiver (CH or Sink) also transmits an ACK for every packet it receives successfully including for duplicates.

3.4.2. Analysis of Node Average Energy Consumption under SW HBH ARQ Protocol

Since the cluster head and common node work in alternate way in cluster based networks, the energy consumption calculation is relatively complicated. The following Theorem 1 gives the average energy consumption calculation.

Theorem 1

If the distance from cluster head to the sink is l, then the total energy consumption for data of all nodes in intra-cluster sent to the cluster head is:

$$ E_{t, total} = 2X_l \sum_{i=1}^{l} (\delta_i) \rho \cdot (2E_{elec} + \rho \cdot l^2) + 2 \rho E_{f} (1^2 + r^2) $$

$$ - 4X_l \sum_{i=1}^{l} (\delta_i) \rho \cdot E_{elec} \cdot \sin(2\rho r + \frac{\pi}{2} - r^3) $$

$$ + 4 X_l \sum_{i=1}^{l} (\delta_i) \rho \cdot E_{elec, f} r $$

Then, after one round data gathering, the node average energy consumption is as Theorem 2.

Theorem 2

In multi-hop cluster based networks, considering the cluster radius is r, after one round data gathering of the entire network, the average energy consumption of node whose distance from the sink is l = hr + x, $E_{t, avg}$ is as the following:

$$ E_{t, avg} = E_{ch} + (D_i + M_i) E_{elec} + (\epsilon \cdot l^2) + D_{1+r} + M_{1+r} E_{elec} + \left(\frac{n}{n-1} \right) E_{t, total} $$

(4)
The network lifetime can be calculated as:
\[
\text{life}_1 = E_{\text{init}} / \max(\mathcal{E}_{1,\text{avg}}) \varepsilon (l_{\text{min}}, R).
\]  

(5)

### 3.4.3. Transport Delay of Multi-Hop Cluster based Network under SW HBH ARQ Protocol

Considering the round-trip time for common nodes send data to CH is \(t_{\text{rtt}}\) (RTT), the retransmission time out is \(t_{\text{rto}}\). Obviously, \(t_{\text{rto}} > t_{\text{rtt}}\). The time for data gathering within the cluster is as the Theorem 3

**Theorem 3**

Considering \(m_i = \zeta(\delta_i)\), the then time for data gathering in intra-cluster is,
\[
t_i^{\text{in}} = (n-1) \left( (m_i - 1) t_{\text{rto}} + \frac{t_{\text{rtt}}}{2} \right)
\]  

(6)

SW-Hop By Hop ARQ protocol is used in data transmission among CHs, as shown in Figure 2. The delay at the transmitter includes the queuing delay \(t_q\) and transport delay \(t\). \(t_q\) is the queuing time for transmission after receiving, \(t\) is the time from sending to receiving. The total delay among CHs is shown in Theorem 4.

**Theorem 4**

The delay \(t_{1,\text{CH}}\), question delay \(t_q\) and transport delay \(E(t_L)\) of CH \(C_l\) at \(l = hr + x\) from the sink is as following:
\[
t_{1,\text{CH}} = t_q + E(t_L) = \frac{\mu^2}{(1-\mu)A_l} + \sum_{k=1}^{(\zeta(\delta_k) - 1)} t_{\text{rto}}(k - 1)t_{\text{rto}}(1 - p)p^{k-1}
\]  

(7)

Note:
\[
t_q = \frac{\mu^2}{(1-\mu)A_l} \mu = \frac{t_{\text{rto}} p \zeta(\delta_k) (1 - p)p^{k-1}}{(k(1-\mu))^k}
\]  

(8)

**Proof**

The data gathering time of node \(v_j\) is \(n((\zeta(\delta_i) - 1)t_{\text{rto}} + t_{\text{rtt}}/2)\), where \(n\) is the node number in the cluster. According to Theorem 4, the delay at CH with distance \(s\) from the sink is \(t_{1,\text{CH}}\), while the routing path of \(v_j\) to the sink is \(R_j\), then the average delay of \(v_j\) in the entire path is the total forwarding delay of each CH.
\[
t_{\text{total}} = \sum \{ t_{1,\text{CH}} \}
\]  

(9)

Therefore, the total transport delay is derived as follows, \(t_{\text{total}} = \sum \{ t_{1,\text{CH}} + t_{\text{rto}}(1 - p)p^{k-1} \} \), then the average delay of \(v_j\) in the entire path is the total forwarding delay of each CH.
\[
t_{\text{total}} = \sum \{ t_{1,\text{CH}} + t_{\text{rto}}(1 - p)p^{k-1} \}
\]  

(10)

**Corollary 2**

Network delay dela \(y_j = \max \{ t_{1,\text{total}} \} \| j \in \{1, n\}\).

**Proof**

Obviously, the network delay is the delay of node with the maximum delay, so dela \(y_j = \max \{ t_{1,\text{total}} \} \), note \(j\) is the number of \(v_j\| j \in \{1, n\}\).

### 3.5. EABC-OLEEO: Enhanced Artificial Bee Colony Algorithm based Optimization of Lifetime and Energy Optimization

The above mentioned network lifetime, total transport delay and energy consumption equation (1) and (2) are optimized using the Enhanced Artificial Bee Colony (EABC) Algorithm. This section, present an EABC Algorithm to meet requirements of the application through trade-offs between the energy consumption and source-to-sink transport delay under SW HBH ARQ protocol for cluster based WSNs.

In this work propose a new algorithm, named as EABC, which combines the good features of GABC and DE. Specifically, the proposed algorithm adopts an evaluation strategy which selects the search method for each individual based on the previous network lifetime, total transport delay and energy consumption values of Clustered WSNs.
chaotic opposition-based population initialization method is employed. The experimental results indicate the proposed approach has better convergence.

3.5.1. Chaotic Opposition-based Population Initialization

Population initialization is a crucial task in EAs because it can affect the convergence speed and the quality of the final solutions. If no information about the solutions is available, then the random initialization is the most commonly used method to generate the candidate solutions (initial population). In this use a chaotic opposition-based population initialization method [Gao et al., 29; Akbari et al., 30] is discussed in Algorithm 3.1 to generate the initial population instead of a pure random initialization.

Algorithm 3.1: Chaotic Opposition-based Population Initialization

1. Set the maximum number of chaotic iteration $K = 300$ and the population size $SN$.
2. $\{ -- Chaotic systems -- \}$
3. for $i = 1$ to $SN$ do
4. for $j = 1$ to $D$ do
5. Randomly initialize variables $ch0, j \in (0, 1)$
6. for $k = 1$ to $K$ do
7. $\phi_{k,j} = \sin(\pi h_{k-1,j})$
8. end for
9. end for
10. $\{ -- Opposition-based learning method -- \}$
11. for $i = 1$ to $SN$ number of cluster heads do
12. for $j = 1$ to $D$ cluster nodes do
13. $\alpha_{i,j} = x_{\min,j} + \phi_{k,j}(x_{\max,j} - x_{\min,j})$
14. end for
15. end for
16. Selecting $SN$ fittest individuals from set the $\{X(SN) \cup OX(SN)\}$ as the initial population

3.5.2. Hybrid Mechanism

According to the solution search equation of ABC, a new candidate is produced by removing the old solution towards a randomly chosen one in the population. On the other hand, the coefficient $\phi_{i,j}$ is a uniform random number in [-1, 1] and $X_i$ is a randomly selected solution from population. In order to improve the exploitation and take advantage of the information of the global best (gbest) solution to guide the search of the candidate solutions, Zhu & Kwong [31] proposed a modified search equation as follows

$$v_{i,j} = x_{i,j} + \phi_{i,j}(x_{i,j} - x_{\min,j}) + \psi_{i,j}(y_i - x_{i,j}) \quad (11)$$

where the third term in the right-hand side of Eq. (11) is a new added term called gbest term, $y_i$ is the jth element of the global best solution $Y$, $\psi_{i,j}$ is a uniform random number in [0, 1.5]. According to Eq. (11), the gbest term can drive the new candidate solution towards the global best solution. Therefore, the modified solution search equation described by Eq. (11) can improve the exploitation of ABC. Then, a gbest-guided ABC (GABC) was proposed in Zhu & Kwong [31]. However, GABC also suffers from poor convergence and low accuracy when dealing with the complex optimization problems. One possible way to enhance the exploitation ability of the algorithm is to combine ABC [Karaboga & Basturk, 32; Karaboga & Akay, 33; Karaboga & Basturk, 34] with another search technique. Being simple, fast, and easy to use, DE can be considered as a good choice for this purpose.

The integration of DE and GABC, named EABC, is designed by the evaluation strategy which selects the search method in a special fashion. GABC and DE in our hybrid approach share a single population. In order to learn good search information from the search process, the evaluation strategy selects one search method for each individual based on the probability which will be introduced in the following part. The selected search method is subsequently applied to the corresponding individual to generate a candidate solution. In other words, if one search method performs better in the previous search, it will have more chance to be used to generate the candidate solutions in the next generation. More specifically, at each generation, the probabilities of choosing each method are summed to 1. Here, $N^G$ GABC and $N^s$ DE denote the number of the candidate solutions generated by GABC and DE which can successfully enter the next generation, respectively. $N^G_{DE}$ and $N^s_{DE}$ represent the number of the candidate solutions generated by GABC and DE which is discarded in the next generation, respectively. The probability of selecting GABC is gradually adapted during the evolution in the following manner.

$$P_{Pro} = \frac{N^G_{GABC} \cdot \left(N^s_{DE} + N^f_{DE}\right)}{N^G_{GABC} \cdot \left(N^s_{DE} + N^f_{DE}\right) + N^s_{DE} \cdot \left(N^G_{GABC} + N^f_{GABC}\right)} \quad (12)$$

Thus, the probability of selecting DE is 1-$Pro$. The roulette wheel selection is used to select the search method based on the probabilities. Clearly, the larger Pro is, the larger probability of applying GABC to generate candidate solutions at the current generation is. The evaluation strategy here is an adaptation mechanism to select one search algorithm form GABC and DE by the feedback from the current state of the search process.

Based on the above description, the framework of the proposed EABC is summarized in Algorithm 4.2. Accordingly, ABC combined with DE is called as EABC which replaces GABC with ABC to update the current solution in line 11 of Algorithm 3.2.

Algorithm 3.2: Proposed EABC-OLEEEO Algorithm

1. Create an initial population $\{X_i \mid i = 1, 2, \ldots, SN\}$ by Algorithm 4.1, evaluate the function values by network lifetime, total transport delay and energy consumption of the population $\{f_i \mid i = 1, 2, \ldots, SN\}$
2. While (stopping criterion is not met, namely $G < G_{Max}$ do
3. Calculate the probability value $Pro$ based on Eq. (12)
is broadcasted, and nodes in intracluster adopt the same mechanism and continue until the reliability meets the requirement $\delta_1$.

2) As for data transmission of inter-clusters, the improved protocol is that the CH returns $n$ ACK for each data packet it receives this is called multi-ACK, see Figure 3.

![Figure 3: Transmission among CHs under BCNM/A](image)

### 3.6.2. Analysis of the Lifetime for BCNM/A Protocol

Under the BCMA protocol, after each data gathering in intra-cluster and the broadcasting by CH (one broadcasting or multi-broadcastings), such process is called one round.

### 3.6.3. Analysis of the Transport Delay for BCNM/A Protocol

The following analyzes the transport delay under BCNM/A protocol, similarly, the node transport delay includes the delay of data gathering within the cluster and the delay of data sent to the sink. The more details of the BCNM/A protocol are discussed in the recent work [Dong et al., 35].

### IV. SIMULATION RESULTS

In this chapter the proposed protocol is simulated using Network Simulator (NS2) [Dong et al., 35; Issariyakul & Hossain, 36; Quintero et al., 37]. Without loss of generality, the parameters are $p = q = 0.3$, $\delta_1 = 0.9$, $R = 500$ m, 1,000 nodes are deployed. The retransmission protocol is called SW-ARQ for short. Broadcasting combined with one-NACK or ACK deployed within the cluster is called BCON/A for short. Broadcasting combined with multi-NACK or ACK deployed both in the cluster and among CHs is called BCNM/A for short. NS-2 is a discrete event simulator targeted at networking research. ns-2 provides substantial support for simulation of TCP, routing, and multicast protocols over wired and wireless (local and satellite) networks. Network Simulator 2.34 (ns-2) [Siraj et al., 38; Wegener et al., 39; Teerawat & Ekram, 40] is a discrete event driven simulator developed at UC Berkeley. It is part of the VINT project.

The goal of ns-2 is to support networking research and education. It is suitable for designing new protocols,
comparing different protocols and traffic evaluations. ns-2 is developed as a collaborative environment. It is distributed freely and open source. A large amount of institutes and people in development and research use, maintain and develop ns-2. This increases the confidence in it. Versions are available for FreeBSD, Linux, Solaris, Windows and Mac OS X. Figure 4 shows the simplified user’s view of ns-2. ns-2 is built using object oriented methods in C++ and Object oriented variant of Tool command language (Tcl). ns-2 interprets the simulation scripts written in Object Tool command language (OTcl) [Wegener et al., 39]. A user has to set the different components (e.g. event scheduler objects, network components libraries and setup module libraries) up in the simulation environment. The user writes his simulation as an OTcl script, plumbs the network components together to the complete simulation. If he needs new network components, he is free to implement them and to set them up in his simulation as well. The event scheduler as the other major component besides network components triggers the events of the simulation (e.g. sends packets, starts and stops tracing). Some parts of ns-2 are written in C++ for efficiency reasons. The data path (written in C++) is separated from the control path (written in OTcl). Data path object are compiled and then made available to the OTcl interpreter through an OTcl linkage (tool command language with class (tclcl)) which maps methods and member variables of the C++ object to methods and variables of the linked OTcl object. The C++ objects are controlled by OTcl objects. It is possible to add methods and member variables to a C++ linked OTcl object.

Then, after running this script file in the simulator, one has output trace files which record all data packets that are dropped, received and sent by MAC layers or interface queues. These trace files are parsed to extract information needed to measure the protocol performance such as the packet delivery ratio, the average end-to-end delay and the average packet hop counts. A performance figure can be plotted later.

4.2. Performance Evaluation Metrics

The proposed EABC-OLEEO algorithm is compared with the existing protocols such as Send and Wait Automatic Repeat reQuest (ARQ) protocol (SW-ARQ) and BCMN/A. The performance of the proposed EABC-OLEEO algorithm is evaluated based the network routing performance metrics such as Packet Delivery Ratio(PDR), Transmission delay, network lifetime and energy consumption.

4.2.1. Packet Delivery Ratio (PDR)

PDR is the ratio of the number of delivered data packet to the destination. This illustrates the level of delivered data to the destination.

\[
PDR = \frac{\text{number of packets receive}}{\sum \text{Number of packet send}}
\]

Figure 6 shows the graphical representation of PDR for proposed EABC-OLEEO algorithm, SW-ARQ and BCMN/A protocols. The proposed EABC-OLEEO has higher PDR inspire of time. On the contrary, the packet delivery ratio of existing protocols is low when compared with the proposed protocol. The EABC algorithm is used for selection which gives best path for data transmission. This is the main reason for high PDR in proposed EABC-OLEEO algorithm.

4.2.2. Transmission Delay

The average time taken by a data packet to arrive in the destination is called delay. It also includes the delay caused by route discovery process and the queue in data packet transmission. Only the data packets that successfully delivered to destinations that counted.

Figure 5 shows the procedure to run ns-2 simulation. It first generates a ns-2 OTcl script file, in which one defines mobility pattern, data traffic pattern, network topology, ad hoc protocol, radio propagation mode, and other parameters.
Figure 7: Comparison of Transmission Delay for Different Algorithms

Figure 7 shows the graphical representation of data transmission delay for proposed EABC-OLEEO algorithm, SW-ARQ and BCMN/A protocols. On the contrary, the data transmission delay of existing protocols is higher when compared with the proposed protocol.

4.2.3. Network Lifetime

It is the time span from the deployment to the instant when the network is considered nonfunctional. When a network should be considered nonfunctional is, however, application-specific. It can be, for example, the instant when the first mobile node dies, a percentage of mobile nodes die, the network partitions, or the loss of coverage occurs.

Figure 8: Comparison of Network Lifetime for Different Algorithms

Figure 8 shows the graphical representation of network lifetime for proposed EABC-OLEEO algorithm, SW-ARQ and BCMN/A protocols. The proposed EABC-OLEEO algorithm has higher network lifetime. On the contrary, the network lifetime of existing SW-ARQ and BCMN/A protocols is lower when compared with the proposed EABC-OLEEO algorithm. The best value is selected for data transmission by using EABC-OLEEO algorithm.

4.2.4. Energy Consumption

The node battery power consumption is mainly due to transmission and reception of data packets. Whenever a node remains active, it consumes power. Even when the node sleepy participating in network, but is in the idle mode waiting for the packets, the battery keeps discharging. The battery power consumption refers to the power spent in calculations that take place in the nodes for routing and other decisions. The number of nodes in the network versus average consumed battery power is considered as a metric.

Figure 9: Comparison of Energy Consumption for Different Algorithms

Figure 9 shows the graphical representation of energy consumption for proposed EABC-OLEEO algorithm, SW-ARQ and BCMN/A algorithms. The proposed EABC-OLEEO has lower energy consumption. On the contrary, the energy consumption of existing SW-ARQ and BCMN/A algorithms is higher when compared with the proposed algorithm. The node with high energy is selected and included in the path. This is the main reason for high energy consumption in proposed EABC-OLEEO algorithm.

V. CONCLUSION AND FUTURE WORK

In this work investigate the problem of maximizing the network lifetime under the reliability constraint which is given in terms of the energy, network lifetime and transmission delay. This work a proposed new Enhanced Artificial Bee Colony Algorithm, i.e. EABC, which combines Differential Evolution (DE) with gbest-guided ABC (GABC) by an evaluation strategy with an attempt to utilize more prior information of the previous search experience to speed up the convergence. In addition, to improve the global convergence, when producing the initial population, a chaotic opposition-based population initialization method is employed. However, the resulting optimal EABC algorithm has lesser implementation complexity, and hence we devise a meta-heuristic algorithm that has a lower and tractable complexity. The results demonstrate by simulations that a trade-off
relation exists between the network lifetime maximization and the reliability constraint, and that the proposed EABC algorithm combined with the optimal energy allocation increases the network lifetime significantly. In future work have also confirmed through simulations that the combined power allocation and routing optimization can increase the network lifetime remarkably over the non-optimal algorithms.

REFERENCES


