An Optimal Routing Protocol using Multi-Objective Cultural Algorithm for Wireless Sensor Networks (ORPMCA)

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ABSTRACT:
Wireless Sensor Networks (WSNs) offer viable options for obtaining data from the environment due to their easy configuration and no need for expensive equipment. These networks make it easy to explore the environment by sensing data related to events in the area under consideration and transferring it to the access point. The energy of sensor nodes in wireless sensor networks is limited, which is a major challenge due to the lack of a fixed charge source. Since most of the energy of the sensors is consumed throughout data transmission, the sensors transmitting the most data or transmitting data packets over considerable distances have faster energy than the rest is over. When the energy of a sensor in the network runs out, the operation of the network may be disrupted and critical data in the network with the desired quality may not reach the sink and eventually the main station. Therefore, considering the dynamic topology and distributed nature of wireless sensor networks, designing energy-efficient routing protocols is one of the main challenges. In this paper, an optimal routing protocol using a multi-objective cultural algorithm (ORPMCA) is presented. The proposed protocol uses the fitness function of the cultural algorithm to adopt the optimal cluster head based on the goals of QoS including residual energy, connection quality, delivery rate, and end-to-end delay. Based on the simulation findings, the proposed protocol increases network lifetime by 15% compared to other protocols.

KEYWORDS: Multi-Objective Cultural Algorithm, Wireless Sensor Networks, Routing Protocol.

1. INTRODUCTION

Since there are not such infrastructure as router in the WSNs, sensors are used as routers to transmit data packets, which receive data from the environment [1]. The sensor receives the required energy for sensing data from the environment and transmitting and receiving them from a connected battery that cannot be recharged. The sensor life is determined by duration of network use and the limited energy of the charging source and, therefore, the available energy should be used semi-optimally [2].

The lifespan of a WSN is mainly specified by an average amount of the energy used by wireless sensors in the network. Network lifetime is the period during which a network is available for performance. WSNs must be able to control the overall network lifetime for ensuring data transmission according to the quality of the service standards. The service quality refers to the management of delay, packet loss, and energy consumption in the network and seeks to provide appropriate routing methods to achieve optimal results for these criteria [3]. It can be stated that the use of energy in the WSNs has the greatest role in determining the criteria of quality of service and overall network performance. Due to the fact that the power required for receiving data and measuring data packets is a constant amount in sensors, so the main energy consumed is the force required to send data between sensors, which routing protocols that are aware of energy can manage average energy consumption and network lifetime [3].

Providing optimal routing protocol in the WSNs in such a way that it can improve the existing constraints is as difficult and complicated as NP-Hard optimization problems. Thus, definitive and traditional search algorithms do not have the ability to provide near-optimal solutions at the right time for routing wireless sensor networks. Recently, the ability of the meta-heuristic algorithms has been demonstrated to provide near-optimal solutions for the WSNs with regard to optimizing the constraints that target network quality of

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service criteria [4].

Therefore, an optimal routing protocol is presented for WSNs using a cultural algorithm in the present article. According to our protocol, individuals are considered as the central sensors of the cluster, fitness function of which has the highest value based on quality-of-service goals including residual energy, connection quality, end-to-end delay, and data delivery rate for that sensor. In fact, in each cluster of sensors formed in the areas under consideration, we select the sensor with the highest value of the fitness function as the central sensor of the cluster and is responsible for transmitting data packets. The connection quality is described as the energy consumed to transfer packets from the source node to the current node in addition to the estimated cost of transferring packets from the next node to the destination. The mentioned protocol employs multi-step routing in which the next sensor is dynamically selected in each step. In order to select the next sensor in the network, in addition to the value of the fitness function, a distance from the sensors to the distance to the sink is also considered. It is expected that the proposed protocol will provide optimal global routing for selecting the optimal local sensor in each step considering making a balance in the goals of quality-of-service criteria.

2. LITERATURE REVIEW

Despite the problems and constraints of wireless sensor networks, compared to conventional supervision systems, great advantages of these networks have increased tendency toward their usage. Non-stop handling and non-use of manpower have increased the tendency to use these networks. Advantages of these networks include low cost, ease and speed of implementation, automatic tuning, and scalability. In recent years, numerous research works have addressed the problem of routing in WSNs.

A routing protocol using clustering according to a multi-objective particle swarm optimization algorithm is proposed in reference [5]. In the offered approach, the fitness function of the particle swarm optimization algorithm for selecting the optimal cluster head based on quality-of-service goals including residual energy, link quality, end-to-end delay and delivery rate. The proposed approach has less energy consuming and extends network lifetime due to balancing the goals of quality-of-service criteria than other approaches.

Wu et al. [6] used merging two methods for providing efficient energy management as well as optimized route selection of the presented algorithm known as EHGUC-OAPR (Energy harvesting-based clustering & optimum adaptive performance routing) in 2 steps. According to them, EHGUC selects multiple groups of the node as the cluster heads on the basis of distance, the weighted sum of the rate of energy harvesting, and so on. Their algorithm reduces the size of the cluster and the distance with the base station, thereby minimizing the consumption of intra-cluster energy, which enables greater storage of energy for inter-cluster data processing. Put differently, OAPR applies the energy sustainability of the nodes for selecting as the next hop that is followed by the reliability of the packet transmission.

Nabavi et al. [7] proposed a greedy method to seek out the shortest random path in WSN. The greedy local search method is quicker than other existing methods and reaches the optimal solution in solving some problems. The simulation results show that within the proposed method, the energy consumption of nodes is nearly symmetric and therefore the network lifetime is reduced with a mild slope. Also, the packet transmission delay within the network increases during a balanced manner. Additionally, network deadlocks have been reduced due to local optimizations, and therefore the data delivery rate has increased by approximately 97%. It also shows better performance in terms of evaluation criteria compared to other previous methods.

[8] presented a definition of mobile data collection protocol in order to monitor traffic on the busy highways wherein deployment of energy harvesting sensors is observed. Researchers deployed a mobile sink for collecting data from the sensors across a pre-defined path. Because of the equipment of the sensors with the renewable energy sources, the time to harvest was variable, too. Therefore, researchers developed the maximization problem of data collection for tackling the multi-rate transmission as well as the transmission slot scheduling between the sensor nodes. According to the authors, the problem has been considered to be NP-hard and thus they provided a solution with an offline algorithm, assuming that the sensors profile has global popularity. Moreover, one of the other online-distributed solutions was presented without any universal information of the sensor profile that is more realistic. Ultimately, [8] addressed the measurement of the algorithms' function for showing efficiency.

In addition, fabrication of the energy map [9] for a sensor network was presented in [10] with regard to the prediction of the behavior of the use of energy for all nodes. Sending the periodical energy update information is avoided by the energy-dissipation model through a single message consisting of energy and other information. According to the performed experiments, in the case of stable dissipation of energy from the sensors, the prediction approach shows higher efficiency. Furthermore, performance is degraded by greater randomness of the events observed in the network, thereby curbing the map accuracy. Consequently, this map must re-transmit the model parameters as well as the energy profile to the base station. Therefore, due to the lack of an in-network data aggregation mechanism, energy prediction is improved for nullifying the added cost of retransmission.

In another study, [11] proposed one of the adaptive opportunistic routing (AOR) protocols for achieving higher throughput with a re-gioning scheme. This regioning scheme creates a forwarding region into k-partitions for each sender. In case of receiving the nodes in a certain area by the packet, the nodes forward that in another time-slot if the nodes have adequate energy and the packet cannot experience a successful delivery downstream. key concern on this protocol is the selection of the best possible forwarding alternatives amongst the partitions and maintenance of the coordination overhead and redundant transmission.

In [12], the researchers proposed one of the novel ad-hoc on-demand distance vector routing (AODV) mechanisms with regard to the maximization hop count, which adds a real-time intelligent estimation function to the original AODV protocol for getting information of the max hop of the networks. Therefore, the value of the max-hop of the networks is calculated by the dynamic-adjusting AODV (DA-AODV) on the basis of the max-hop count and dynamically and intelligently sets the parameters with regard to the value of the max hop for enhancing the function of the network. Researchers in [13] addressed delay analysis, as well as the probability of the packet drop, and [14] presented several routing algorithms for wireless networks. The researchers proposed a relatively interconnected mesh-network topology and a routing scheme for the network on chip topology [15]. In addition, [15] showed one of the effective multi-hop MCROB protocols for highway VANET, and [16] adopted the concept of opportunistic routing.

Researchers have also presented one of the LEACH-based cooperative clustering protocols for enhancing the energy harvesting-based wireless sensor network [17]. Therefore, as one of the functions of the energy harvesting ability, duty cycle is used to alternate the function of the cluster head between the nodes in the protocol. Then, these nodes take a data-transmission duty cycle but have no action as a cluster head. Moreover, the nodes employ excessive energy for relaying other packets of the nodes. Finally, an innovative cross-layer cooperative TDMA system is used for optimizing the relaying function.

Nassirpour et al. [18] presented an appreciate clustering method through memetic algorithm. Proposed method includes two stable clustering and data transmission stages. In clustering stage, clusters are organized and in data transmission stage based on schedule, gathered data would be transferred by sensor nodes to cluster head. within the paper, operation of determining cluster heads is assumed to be taken place in base station or sink. Base station or sink as a strong central processing unit with unlimited amount of energy is skilled of categorize information related to energy and position of network nodes in clusters being similar in terms of energy consumption and total amount of work done, based on memetic algorithm.

3. PROPOSED METHOD

Clustering sensor nodes in the WSNs have been proposed as one of the most efficient solutions for declining consumed energy and distribution of data transfer through higher-energy sensor nodes. As a pioneer clustering protocol for wireless sensor networks, the LEACH method [19] in which random selection of cluster heads cannot guarantee the actual position of the cluster head. In other words, the unbalanced distribution of the cluster head prevents the selection of high-energy and optimal sensor nodes for data transfer. Cluster heads may also not be placed in the right position relative to other sensor nodes relating to the cluster, and with a large distance, more energy is lost from the cluster head, which will affect the lifetime of the network. Thus, the first step that can be taken for improving the use of energy in the WSNs is the accurate selection of the location of the optimal sensor nodes and the cluster heads for the task of data transfer between clusters to the sink.

3.1. Cluster distance

The cluster head in the wireless sensor network requires to receive information from the cluster member node. Surrounding the cluster head by the cluster member node in each cluster leads to the nearest distance between the cluster member node and cluster head and the minimum transmission distance. Therefore, the energy consumption of the cluster member node is minimum. Equation 1 expresses the cluster distance model [20].

$$D_{nc} = min(\sum_{m=1}^{M}(\sum_{n=1}^{N} d_{ncluster})) \quad (1)$$

where, M refers to the number of cluster heads, N refers to the number of cluster member nodes of each cluster and $d_{ncluster}$ denotes the Euclidean distance from cluster member node to cluster head.

3.2. Sink distance

Based on the LEACH approach, data fusion is conducted and sent to the sink by the cluster member node on the collected information. The energy consumption reduced by decreasing the transmission distance. Model the distance expressed in equation 2 [20].

$$D_{cs} = min\sum_{m=1}^{M} d_{Csink} \quad (2)$$

where, d_{csink} shows Euclidean distance from cluster node to the sink.

3.3. Overall energy consumption of the network $Energy1$

The overall energy consumption of the network in the clustering stage is expressed in equation 3 [20].

As the cluster head, a message is transmitted by the cluster member node, and a TDMA schedule is transmitted. The cluster member node receives the table, and the data amount is t bit. The energy consumption of cluster head sends information is $E_{cn}(t, d_{cn})$.

$$E_{cn}(t, d_{cn}) = \begin{cases} t(E_{elec} + \tau_f d_{cn}^2), & d_{cn} < d_c \\ t(E_{elec} + \tau_m d_{cn}^4), & d_{cn} \geq d_c \end{cases} \quad (3)$$

In the equation, E_{elec} denotes the energy consumption by the node to transmit 1 bit of data, τ_m and τ_f are the energy consumption of the signal amplifier broadcasting 1 data bit per unit distance in the multipath fading and free space models, respectively. The Euclidean distance from current cluster member to cluster head is represented by d_{cn}. Threshold $d_0 = \sqrt{\frac{\tau_f}{\tau_m}}$ for conversion between communication channel models.

The TDMA table, as well as the t bit information from the cluster head are accepted by the cluster member node, and the t bit data is transmitted to the cluster head supported the TDMA table. The energy consumption by the cluster member node $E_{non-cn}(t, d_{cn})$ is expressed in equation 4 [20].

$$E_{non-cn}(t, d_{cn}) = \begin{cases} t(E_{elec} + \tau_f d_{cn}^2) + t \times E_{elec}, & d_{cn} < d_c \\ t(E_{elec} + \tau_m d_{cn}^4) + t \times E_{elec}, & d_{cn} \geq d_c \end{cases} \quad (4)$$

Finally, the energy consumption of the process for the cluster head accepts the cluster member node sends the information $E_{cn}(t, d_{cn})$.

$$E_{cn}(t, d_{cn}) = tE_{elec} \times \left(\frac{N}{M} - 1\right) \quad (5)$$

The summarization of total energy consumption of the network $Energy1$ in the clustering stage is represented by Eq. (3)-(5).

$$Energy1 = \begin{cases} min\left(tE_{elec} \times \left(\frac{N+2}{M} - 1\right) + \tau_f d_{cn}^2 \times \left(\frac{N}{M} - 1\right)\right), d_{cn} < d_c \\ min\left(tE_{elec} \times \left(\frac{N+2}{M} - 1\right) + \tau_m d_{cn}^4 \times \left(\frac{N}{M} - 1\right)\right), d_{cn} \geq d_c \end{cases} \quad (6)$$

3.4. Network energy consumption balance $Energy2$

The network energy consumption balance consists of two components D_{no} and D_{en}. The variance of the number of cluster member node in each cluster D_{no} is expressed in equation 7. The number of nodes in each cluster moves to the mean number by reducing the value, suggesting the proper balance between the loads per cluster head [20].

$$D_{no} = \frac{\sum_{i=1}^{m}(v_i - u)^2}{m} \quad (7)$$

Where, v_i is the number of cluster member node in the $i-th$ cluster, u is that the average number of cluster member node of every cluster in the network.

The variance of the energy consumption of clustered member modes in every cluster is D_{en}. The energy consumption in the clusters becomes more average by reducing the value. The relation is [20]:

$$D_{en} = \frac{\sum_{i=1}^{m}(E_i - u_e)^2}{m} \quad (8)$$

Where, E_i is the total energy consumption in the $i-th$ cluster and u_e is the average of the energy consumption of every cluster.

The network energy consumption balance is expressed in equation 9 [20].

$$Energy2 = min(D_{no} + D_{en}) \quad (9)$$

3.5. Cultural algorithm (CA)

Cultural algorithm [21] has been presented by Robert Reynolds as one of the evolutionary algorithms (1994) for simulating the human community. The simulation process is based on low- and high-level evolution, which has higher accuracy in comparison to the conventional evolutionary algorithms in particularly reflecting the intelligent evolution of the species. Moreover, the algorithm provides results closer to the optimal solution in solving some problems compared to traditional evolutionary algorithms. Hence, an optimal routing protocol is introduced using the cultural algorithm for the WSNs for increasing the lifetime of the network. Fig. 1 indicates the general structure of this algorithm.

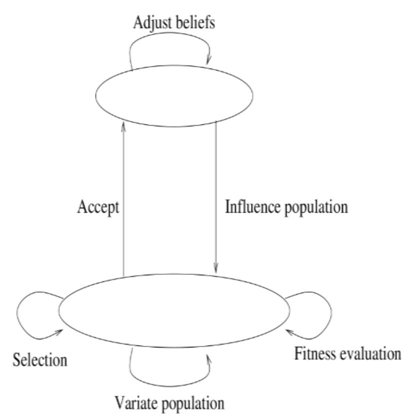

Fig. 1. Cultural algorithm.

Since the objectives available in the network may be contradictory and improving one objective may reduce optimality of other objectives, conventional criteria for wireless sensor networks are inadequate. Thus, multi-objective criteria are considered for achieving the appropriate route from the source node to the sink. In this proposed protocol it is attempted to make a balance among objectives of the network that might be contradictory so that optimality of all objective is taken into account. Therefore, the mentioned parameters are considered for multi-objective performance in order to discover the most optimum route from the source node to the sink. Finally, the evaluation function is presented in equation 10.

$$
\begin{gathered}
\mathrm{F} = \mathrm{Min} \sum_{\mathrm{i}}^{\mathrm{n}} \sum_{\mathrm{j}}^{\mathrm{k}} D_j - D_i + \left(tE_{elec_i} + \tau_f d_{cn_j}^2\right) + \left(\left(\varepsilon_e * n_i * d_{ij}^2\right) + \left(K * D_{jK}^2\right)\right) \\
\sum_{j=1}^{k} D_j \geq \alpha \\
\sum_{i=1}^{n} D_i \leq \beta
\end{gathered}
\tag{10}
$$

According to equation 10, in each upgrade round of the cultural algorithm proposed in the route selection step, the node that minimizes the value of the F function in the cluster is chosen as the cluster head that assumes the data transfer process from the sensor nodes relating to the cluster to the sink. During several steps of the upgrade, the value of the fitness function may be minimal for a node and the cluster head may not change over several steps. However, as time passes and packets are transferred, the cluster head energy decreases and must be replaced. Fig. 2 indicates the flowchart of the protocol proposed in this paper.

4. RESULTS AND DISCUSSION

ORPMCA shows considerable significant advancement in the selection of the most optimal route for the message regarding the transmitted bits and longevity (with the selection of the nodes with the maximum energy at each step, the prolonged life of the path is observed). This study simulates ORPMCA with the first-order energy model on 10 static topologies. With regard to the simulation outputs, ORPMCA enhances the lifetime of the network via balancing the use of energy.

We use MATLAB for simulating ORPMCA. Therefore, the simulation environment is thoroughly illustrated in this experiment. Then, simulation is applied on a 500m×500m area with 4 distinct node settings (80/100/120/150). All of the sensor nodes are initialized with the energy value of 0.5 J and the threshold value is set to be 0.2 J that is controlled prior to transmitting data. In case of falling a node's residual energy under the short threshold value, we consider the communication link to be broken. The simulation parameter employed in the present research is summarized in Table 1.

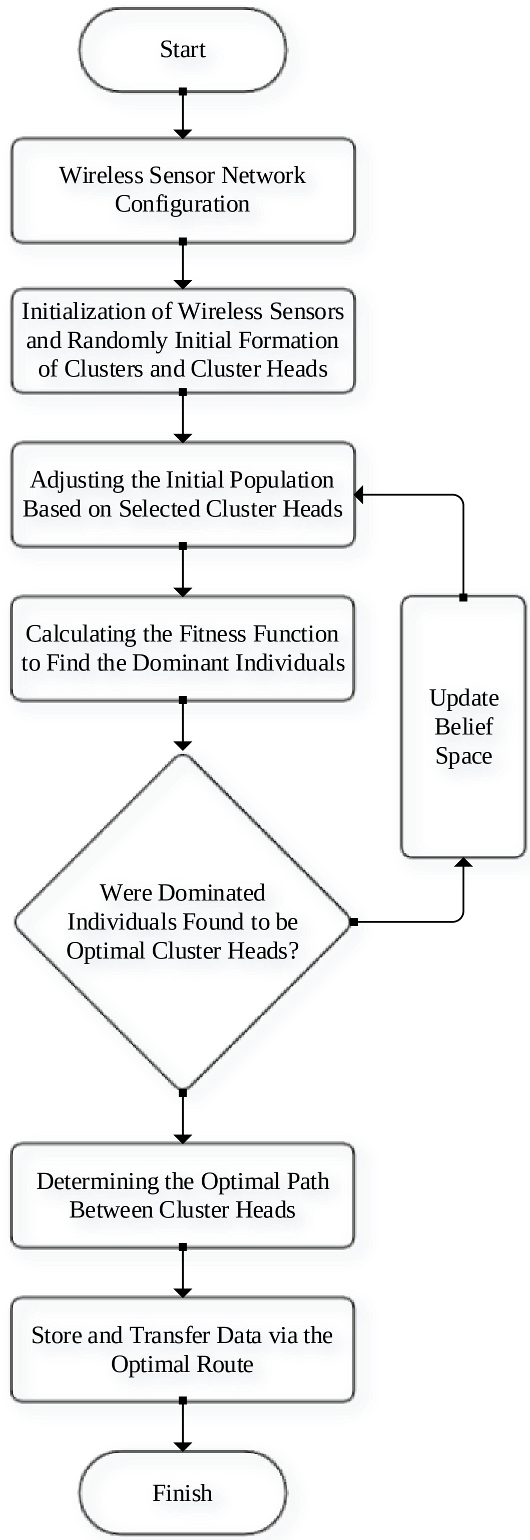

Fig. 2. Flowchart of proposed method.

Table 1. Some factors employed for simulating.

Simulation Parameters	Values
Area	500×500 m^2
Number of the nodes	80, 100, 120, 150
Number of Gateways	45, 60, 75, 90
Transmission range	150 m
Initial energy	0.5 J
Threshold energy	0.2 J
Message length	100 bytes
Number of iterations	30

Thus, in the present paper, since it is attempted to reduce consumed energy, decrease latency, and increase network lifetime, these criteria are considered. Fig. 3 indicates residual energy in sensor nodes of the network.

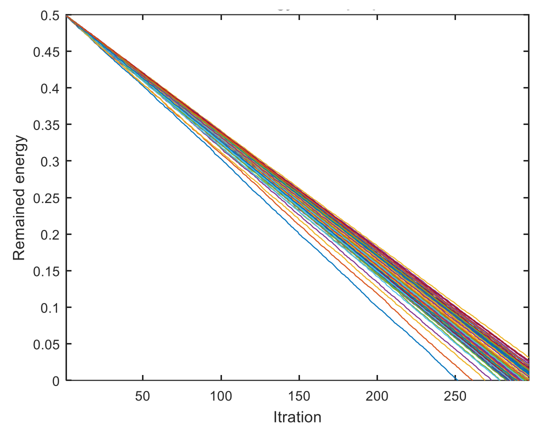

Fig. 3. Remained energy of sensor nodes.

Another criterion employed for evaluating the proposed protocol is network throughput. Fig. 4 displays the throughput rate in the network.

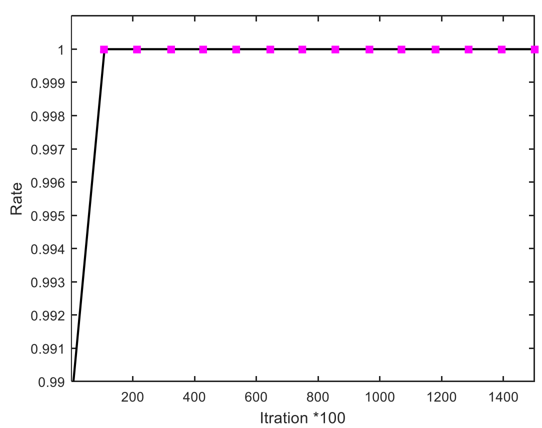

Fig. 4. Network throughput rate.

As observed in Fig. 4, network throughput rate is high in network and it is in average as 99.89%.

The last criterion used for the evaluation of the proposed protocol is the end-to-end delay of the sensor nodes in the network. Considering the fact that the transmission coefficient of a packet is constant for the sensors, the main reason for the delay in the end-to-end transmission is the distance between the sensor nodes. Since in our protocol, a transfer occurs between the sensor nodes and the cluster heads, a shorter distance from the cluster heads to other sensor nodes means an accurate clustering and shorter average inter-cluster distances. The end-to-end delay diagram of 100 sensor nodes is shown in Fig. 5.

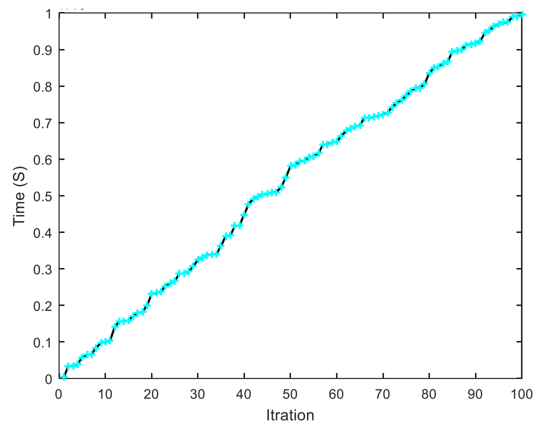

Fig. 5. End-to-end delay of sensor nodes.

As observed in Fig. 5, an average delay of 1ms per cycle is observed for 100 sensor nodes in the proposed protocol. This small value denotes the small distance from the cluster heads to the sensor nodes belonging to the cluster.

Moreover, GA-based algorithm [22] and another three algorithms PSO [23], GLBCA [24], and LDC are implemented to be compared [25].

Firstly, algorithms are run to compare the network lifetime via changing the sensor nodes.

Fig. 6 compares our algorithm with PSO, GA, LDC as well as GLBCA with regard to the life of the network.

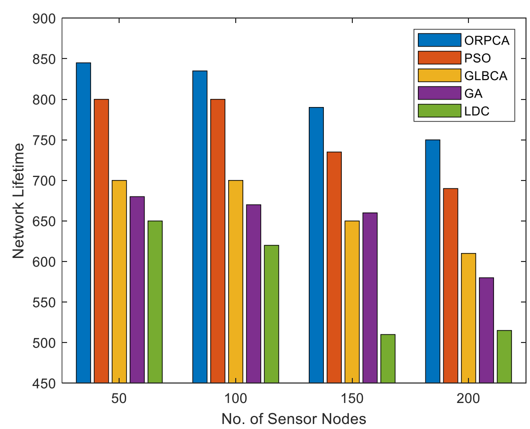

Fig. 6. Comparison in terms of the lifetime of network.

Higher lifetime of the network can be observed from Fig. 6 in comparison to PSO, LDC, GA and GLBCA-based algorithms.

Fig. 7 depicts a comparison between the use of the network energy. Despite the same amount of energy is used by our algorithm, PSO, the GA and GLBCA-based algorithms, we assume outperformance of this new algorithm because of the use of greater energy by the increased number of the active sensor nodes in the network in comparison to the other nodes. In addition, we observed lower consumption of energy by LDC because of the respective sensor assignment approach.

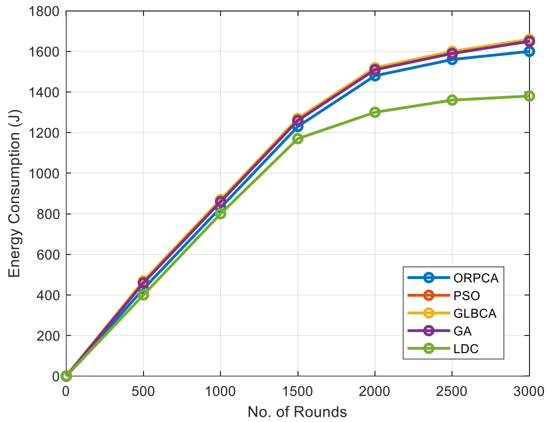

Fig. 7. Comparison between the use of energy.

With regard to Fig. 8, the number of the data packets obtained via the base station in LDC decreased in comparison to our new algorithm and other algorithms. Therefore, this new algorithm has been shown to be superior to other algorithms.

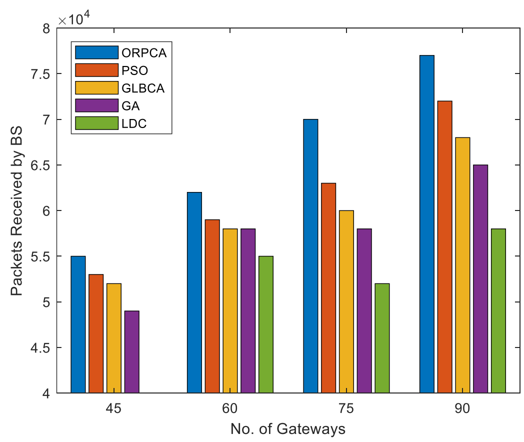

Fig. 8. Comparison between the total data packets collected by the base station.

5. CONCLUSION

In the present study, an optimal routing protocol is proposed for WSNs with the utilization of the multi-objective cultural algorithm. Within the proposed protocol, individuals are considered as the central sensors of the cluster, fitness function of which has the best value based on quality-of-service objectives for that sensor. In fact, in each cluster of sensors formed in the areas under consideration, the node with the highest value of the fitness function is chosen as the cluster head and is liable for transmitting data packets. Results of simulation indicate that the protocol supported in the present paper has a lower average consumed energy and longer lifetime compared to other previous protocols. The lower use of energy and prolonged lifetime of the proposed protocol suggests the balance of consumed energy in this protocol ad later death of sensor nodes, which ends up from accurate clustering and observation of main network factors. The proposed protocol could achieve optimal outcomes through developing balance among several objectives in the network routing, which shows considerable improvement compared to the previous protocols in this area.

REFERENCES

[1] S. Adhyapok and H. K. D. Sarma, **“Review on QoS Aware Routing Protocols for Multi-Channel Wireless Sensor Network,”** in *2nd International Conference on Innovative Mechanisms for Industry Applications, ICIMIA 2020 - Conference Proceedings*, Mar. 2020, pp. 503–509.

[2] W. Lu, H. Zhao, and H. Zhao, **“Distributed Energy Balancing Routing Algorithm in Wireless Sensor Networks,”** *Springer, Berlin, Heidelberg*, pp. 227–232, 2012.

[3] N. Z. Cedeno, O. P. Asqui, and E. E. Chaw, **“The performance of QoS in wireless sensor networks,”** in *Iberian Conference on Information Systems and Technologies, CISTI*, Jun. 2019, Vol. 2019.

[4] C. W. Tsai, T. P. Hong, and G. N. Shiu, **“Metaheuristics for the Lifetime of WSN: A Review,”** *IEEE Sensors Journal*, Vol. 16, No. 9, pp. 2812–2831, 2016.

[5] S. R. Nabavi, N. Osati Eraghi, and J. Akbari Torkestani, **“Wireless Sensor Networks Routing Using Clustering Based on Multi-Objective Particle Swarm Optimization Algorithm,”** *Journal of Intelligent Procedures in Electrical Technology*, Vol. 12, No. 47, pp. 49–67, Mar. 2021.

[6] Y. Wu and W. Liu, **“Routing protocol based on genetic algorithm for energy harvesting-wireless sensor networks,”** *IET Wireless Sensor Systems*, Vol. 3, No. 2, pp. 112–118, Jun. 2013.

[7] S. R. Nabavi, N. Osati Eraghi, and J. Akbari Torkestani, **“WSN Routing Protocol Using a Multi-Objective Greedy Approach,”** *Wireless Communications and Mobile Computing*, Vol. 2021, 2021.

[8] X. Ren, W. Liang, and W. Xu, **“Use of a mobile sink for maximizing data collection in energy harvesting sensor networks,”** in *Proceedings of the International Conference on Parallel Processing*, pp. 439–448, 2013.

[9] R. A. F. Mini, A. A. F. Loureiro, and B. Nath, **"Energy map construction for wireless sensor network under a finite energy budget,"** in *ACM MSWiM 2004 - Proceedings of the Seventh ACM Symposium on Modeling, Analysis and Simulation of Wireless and Mobile Systems*, pp. 165–169, 2004.

[10] R. A. F. Mini, M. do Val Machado, A. A. F. Loureiro, and B. Nath, **"Prediction-based energy map for wireless sensor networks,"** *Ad Hoc Networks*, Vol. 3, No. 2, pp. 235–253, Mar. 2005.

[11] Z. A. Eu and H. P. Tan, **"Adaptive opportunistic routing protocol for energy harvesting wireless sensor networks,"** in *IEEE International Conference on Communications*, pp. 318–322, 2012.

[12] X. Zhang, Z. H. Qian, Y. Q. Guo, and X. Wang, **"An efficient hop count routing protocol for wireless ad hoc networks,"** *International Journal of Automation and Computing*, Vol. 11, No. 1, pp. 93–99, Feb. 2014.

[13] N. Meghanathan and N. Meghanathan, **"Impact of the Gauss-Markov mobility model on network connectivity, lifetime, and hop count of routers for mobile Ad-hoc networks,"** *J. NETW*, pp. 509-516.

[14] Y. Zhao, Y. Chen, B. Li, and Q. Zhang, **"Hop ID: A virtual coordinate-based routing for sparse mobile ad hoc networks,"** *IEEE Transactions on Mobile Computing*, Vol. 6, No. 9, pp. 1075–1089, Sep. 2007.

A. F. Mini, A. F. Mini, B. Nath, and A. A. F. Loureiro, **"A Probabilistic Approach to Predict the Energy Consumption in Wireless Sensor Networks,"** *IN IV WORKSHOP DE COMUNICAO SEM FIO E COMPUTAO MVEL. SO PAULO*, pp. 23-25.

[15] S. S. Lam and C. Qian, **"Geographic routing in d-dimensional spaces with guaranteed delivery and low stretch,"** in *Performance Evaluation Review*, Vol. 39, No. 1 SPEC. ISSUE, pp. 257–268, 2011.

[16] M. S. Bahbahani and E. Alsusa, **"A Cooperative Clustering Protocol with Duty Cycling for Energy Harvesting Enabled Wireless Sensor Networks,"** *IEEE Transactions on Wireless Communications*, Vol. 17, No. 1, pp. 101–111, Jan. 2018.

[17] S. Nassirpour and S. Tabatabaei, **"Distributed Routing Protocol in Wireless Sensor Networks through Mimetic Algorithm and Time-Sharing Approach to Select Cluster Head,"** *Majlesi Journal of Telecommunication Devices*, Vol. 9, No. 2, pp. 81–91, Jun. 2020.

[18] Z. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, **"Energy-efficient communication protocol for wireless microsensor networks,"** in *Proceedings of the Hawaii International Conference on System Sciences*, pp. 223, 2000.

[19] D. Wu, S. Geng, X. Cai, G. Zhang, and F. Xue, **"A many-objective optimization WSN energy balance model,"** *KSII Transactions on Internet and Information Systems*, Vol. 14, No. 2, pp. 514–537, 2020.

[20] R. G. Reynolds, **"An introduction to cultural algorithms,"** in *Proceedings of the third annual conference on evolutionary programming*, Vol. 24, pp. 131–139, 1994.

[21] P. Kuila, S. K. Gupta, and P. K. Jana, **"A novel evolutionary approach for load balanced clustering problem for wireless sensor networks,"** *Swarm and Evolutionary Computation*, Vol. 12, pp. 48–56, Oct. 2013.

[22] E. Rezaei and S. Ghasemi, **"Energy-Aware Data Aggregation in Wireless Sensor Networks Using Particle Swarm Optimization Algorithm,"** *American Journal of Information Science and Computer Engineering*, Vol. 4, No. 1, pp. 1–6, 2018.

[23] C. P. Low, C. Fang, J. M. Ng, and Y. H. Ang, **"Efficient Load-Balanced Clustering Algorithms for wireless sensor networks,"** *Computer Communications*, Vol. 31, No. 4, pp. 750–759, Mar. 2008.

A. Bari, S. Wazed, A. Jaekel, and S. Bandyopadhyay, **"A genetic algorithm based approach for energy efficient routing in two-tiered sensor networks,"** *Ad Hoc Networks*, Vol. 7, No. 4, pp. 665–676, Jun. 2009.