A Novel Cluster-based Routing Protocol Wireless Sensor Networks using Spider Monkey Optimization

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***Abstract*— With rapid development, wireless sensor networks (WSNs) have been focused on improving the performance consist of energy efficiency, communication effectiveness, and system throughput. Many novel mechanisms have been implemented by adapting the social behaviors of natural creatures, such as bats, birds, ants, fish and honeybees. These systems are known as nature inspired systems or swarm intelligence in in order to provide optimization strategies, handle large-scale networks and avoid resource constraints. Spider monkey optimization (SMO) is a recent addition to the family of swarm intelligence algorithms by structuring the social foraging behavior of spider monkeys. In this paper, we aim to study the mechanism of SMO in the field of WSNs, formulating the mathematical model of the behavior patterns which cluster-based Spider Monkey Optimization (SMO-C) approach is adapted. In addition, our proposed methodology based on the Spider Monkey's behavioral structure aims to improve the traditional routing protocols in term of low-energy consumption and system quality of the network.**

Keywords*— *Wireless Sensor Networks, Swarm Intelligence, Spider Monkey Optimization, Routing Protocols

I. INTRODUCTION

Swarm Intelligence (SI) is an Artificial Intelligence technique and used to solve complex optimization problems by simulating behavioral structures of neutral creatures or artificial systems. These techniques demonstrate the desirable properties of interpretability, scalability, robustness, effectiveness and efficiency. Previous studies [1-5] has shown that SI based algorithms have potential to achieve better solutions in real world issues, especially in the field of Mobile Ad hoc Networks (MANETs) and Wireless Sensor Networks (WSNs). In recent research, other swarms such as elephants, spiders, termites, and monkeys have involved to wireless infrastructures for implementing novel routing protocols in WSNs. As known as the biggest land mammals, Elephants form a well-organized group structure with no more than 50 individuals and follow the lead by the oldest female of the group [6]. Each group develops some of the quotidian actions include group defense, offspring care, resource acquisition, and teamwork. Several proposal based on Elephant Swarm Optimization (ESO) model are presented in [7-9]. When hunting a prey, the social spider presents a very impacting behavior structure by dancing on the spider web without direct communication. Once a prey is determined, all spiders move together to hunt it. This behavior was used in [10] to detect misbehaving sensor nodes in WSNs. Termite Colony Optimization (TCO) is a population-based method, which is for optimizing numerical functions. It is inspired from intelligent behaviors of termites in nature. The study of behavioral structure of termite has exposed significant successes in the communication capabilities as compared to birds, ants, honeybees and bats. Termite-Hill [11] has been proposed to demonstrate the autocatalytic behavior of termites to efficiently find the sink and also to balance the network energy at any location and anytime. Monkey is very interesting and fascinating due to its behavioral skills and intelligence. In the group, the oldest female generally becomes leader and responsible for every kind of decision [12]. Once the leader dies, the rank is automatically passed to the next monkey in the hierarchy. The study of monkey's social behavior shows the potentiality and possibility in various applications such as antenna design [13] and routing protocol implementation in WSNs [14]. Numerous schemes and designs have been proposed for utilizing swarm intelligence to handle wireless sensor networks relate issues. Spider Monkey Optimization (SMO), a new addition to the swarm intelligence family, is inspired by the foraging behavior of spider monkeys.

The rest of the paper is organized as follows. Section II introduces and explains the main features of the original Spider Monkey Optimization technique and its mathematical formulation. Section III presents and discusses the proposed SMO-C methodology. In Section IV, the simulation environment is presented in detail as well as the comparison results on our approach against the baseline method. The paper is concluded in Section V along with our future directions.

II. SPIDER MONKEY OPTMIZATION (SMO) ALGORITHM

A. Monkey Intelligence based Applications

In zoology, monkeys are known as 'dry nosed' primates, a paraphyletic group generally consisting of more than 200 living species [16]. Kumar and Kusuma [14] proposed a

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hybrid approach based on the social behavior of monkeys to improve the traditional low-energy adaptive clustering hierarchy (LEACH) protocol [17]. This protocol presents a good energy aware strategy at the cluster head selection phase and it can be easily adapted in WSNs. Spider monkeys are a new addition to the New World monkeys. Scientists are fascinated by their intelligence and many algorithms were developed in the collective behavior of spider monkeys. Kumar and Kumari [12] proposed a new strategy to update position of female monkeys during foraging phase by incorporating fitness of individuals. It is shown better solutions exploits the search space in the certain area and proven that the proposed approach is always faster than basic Spider Monkey Optimization algorithm. Ali et al. [13] presented the efficiency of the SMO by comparing to traditional optimization techniques in solving electro-magnetics and antennas problems.

B. Major Steps of Spider Monkey Optimization (SMO)

Spider monkey optimization is promising in exploitation and exploration of local search in our previous survey [5]. According to recent studies, SMO is a well-organized algorithm and has been proved efficient and reliable in most cases. Spider monkey optimization is simple, yet powerful as well as a population based search strategy and analogous to Artificial Bee Colony (ABC) [15] approach in characteristics. It contains seven major steps, and the complete description of every phase is summarized in this subsection [18-19].

1) *Population Initialization Phase (PIP):* A population of M spider monkeys (SM) initialized, where i = {1, 2, ..., m}. Every spider monkey is randomly distributed,

$$SM_{ij} = SM_{minij} + rand[0, 1] * (SM_{maxij} - SM_{minij}) \quad (1)$$

where SM_{ij} indicate i^{th} SM in j^{th} dimension. SM_{minij} and SM_{maxij} denote lower and upper bounds of SM_i in j^{th} direction correspondingly.

2) *Local Leader Phase (LLP):* The LLP phase starts right after PIP step. Based on the local leader and individual group members (SMs) experience to adjust the new location. Greedy selection is applied by comparing between new location and current location using fitness function.

$$SM_{newij} = SM_{ij} + p_i*(LL_{kj} - SM_{ij}) + (1-p_i)*(SM_{rj} - SM_{ij}) \quad (2)$$

$$P_i = 0.9 * (Fitness_i / Fitness_{max}) + 0.1 \quad (3)$$

where LL_{kj} correspond to the k^{th} local group leader location in j^{th} dimension. SM_{rj} denotes the r^{th} SM. Here p_i is probability of i^{th} solution. Fitness can be computed by various objective methods.

3) *Global Leader Phase (GLP):* After LLP phase, Global Leader Phase starts based on global leader and members of local group's experience, using Eq. (4) to modify their position,

$$SM_{newij} = SM_{ij} + p_i*(GL_j - SM_{ij}) + (1-p_i)*(SM_{rj} - SM_{ij}) \quad (4)$$

where GL_j represents the position of global leader in j^{th} dimension and $j \in \{1, 2, 3, \dots, D\}$, which is a random index.

4) *Global Leader Learning (GLL) Phase:* In this phase, global leader is updated by an algorithmic paradigm, greedy selection, which is making the optimal solution in the population at each stage i.e., the position of the current spider monkey having highly fitted solution in the selected population and labeled as the newly generated position of the global leader. Furthermore, the *GlobalLimitCount* threshold increases by 1 whether the position of global leader is updated or not.

5) *Local Leader Learning (LLL) Phase:* In this phase, the local leader position is updated using same strategy as GLL phase. The LocalLimitCount value is incremented by 1 due to the comparison of the updated position of the local leader with its previous position.

6) *Local Leader Decision (LLD) Phase:* After the learning phase, decision taken upon the updating of any local leader position. If it is not updated up to the *LocalLimitCount* value, then all members within the group modernize their positions by random initialization or based on the global leader and local leader experience, shown in Eq. (5),

$$SM_{newij} = SM_{ij} + p_i*(GL_j - SM_{ij}) + (1-p_i)*(SM_{rj} - LL_{kj}) \quad (5)$$

7) *Global Leader Decision (GLD) Phase:* After GLL, if the position of global leader is not updated up to a specific iterations value, known as *GlobalLimitCount*, then the population is divided into smaller groups based on global leader's decision.

In general, exploration and exploitation are primary factors of the population-based optimization strategies such as [15, 20, 21]. These factors indicate the ability to trace the global optima by investigating the variety of unidentified solutions in the search area. Bio-inspired systems are tending to be included in new architectures due to the following reasons,

(i) Simple to design and interpret with basic rules
(ii) Adaptive to medium topological change
(iii) Efficiently manage limited resources

III. CLUSTER-BASED SMO ROUTING PROTOCOL

The goal of our approach, cluster-based Spider Monkey Optimization (SMO-C), is to improve the network performance and reduce energy consumption. For designing new protocol approach, it allows us to space out lifespan of the sensor node due to its limited battery life and other resource constrains. In cluster-based protocol, cluster head is assigned to collect data from its surrounding nodes and passes it on to the base station as shown in Fig. 1.

In SMO-C, cluster head (CH) is selected based on the residual energy of the sensor node. This election approach can be visualized in a group of spider monkeys, contain both females and males. In nature, the female monkey is always the leader; it ranks by its fitness and fertility [14]. If the current leader dies, the authority will pass to the next female monkey.

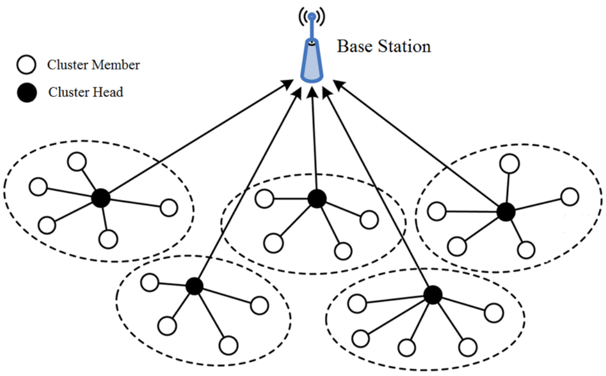

Fig. 1. Cluster-based wireless sensor networks (WSNs)

For redundant cluster heads without any nodes attached to it, it will automatically assigned to the nearest cluster. This feature is inspired from the fission-fusion behavioral structure of spider monkeys.

A. Cluster Head Selection

Cluster-head selection process is dynamic because the duty of cluster-head rotates. SMO-C protocol chooses cluster head by user-specific threshold as shown in Eq. (6),

$$CH_{initiate} = P_i * P_{CH} \tag{6}$$

where P_i and P_{CH} are the probability of i^{th} solution for every group member as shown in Eq. (3) and Percentage of cluster heads in each iteration, respectively.

According to LEACH, some of nodes cannot be nominated as cluster heads in the initialization stage. Because the process of electing cluster head in set-up phase is random. Hence, the SMO-C approach is designed at selecting the cluster heads with better location to extend the overall network performance in terms of low energy loss and less dead nodes. The execution flow of the cluster formation in SMO-C is shown in Fig. 2 [5].

B. First Order Radio Model

In SMO-C, we deploy first order radio model to approximate energy consumption of the sensor nodes. Assuming each sensor node is not able to consume any energy when it is not receiving or sending any packet. We present the low-energy radio model, which was adapted in the original LEACH [17] protocol as well as the EAMMH [22] cluster algorithm. Different protocols take advantages of different assumptions on the radio model, such as energy dissipation in transmit mode or receive mode. We adopt a naïve model where the radio consumes E_{Tx} = 50 nJ/bit to run the transmitter or receiver, and the amplifier losses of the sending node is set as E_{amp} = 100 pJ/bit/m^2. The energy dissipated by the node to receive or send 1 bit packet is E_{elec}. When the condition satisfies the communication distance d and the energy consumed to send a k bit packet, the radio expends,

$$\begin{aligned} E_{Tx}(k, d) &= E_{elec} * k + E_{fs} * k * d^2 \qquad &, d < d_0 \\ &= E_{elec} * k + E_{amp} * k * d^4 \qquad &, d \geq d_0 \end{aligned} \tag{7}$$

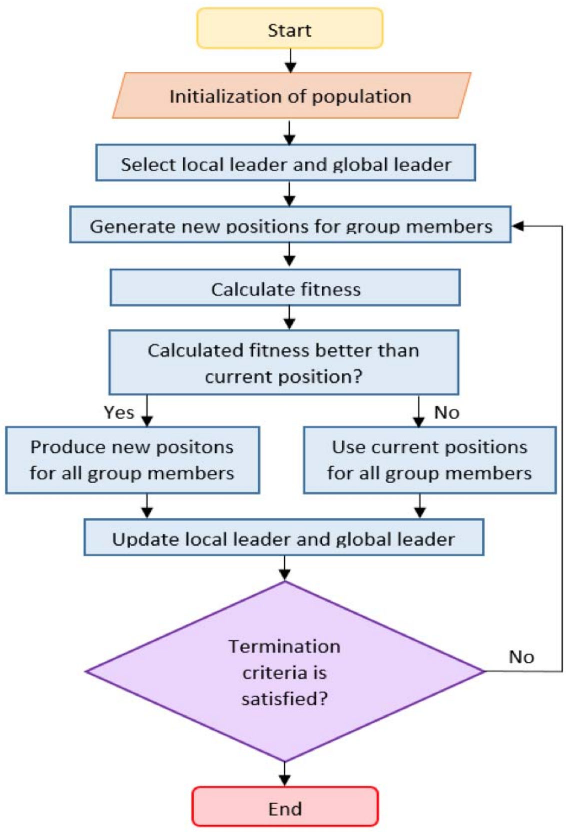

Fig. 2. Execution flow of the cluster formation in SMO-C

and to receive this bit packet, the radio expends,

$$E_{Rx}(k) = E_{elec} * k \tag{8}$$

raio channel is symmetric by assuming that the enrgy reuired to transmit a data packet from node SN_i to SN_j is the same as the energy required from SN_j to SN_i. Futhermore, all nodes are snesing the environment at a fixed rate, which is a data-driven simulation.

C. Energy Utilization

There are many network routing protocols proposed for wireless sensor networks. We examine two of these protocols as our baseline approaches, LEACH [17] and EAMMH [22]. In SMO-C, we propose an energy aware routing protocol. In some existing protocols [19], nodes route message through intermediate nodes instead of direction communication through cluster head. In this matter, the intermediate nodes are known as our local leaders within a group of spider monkeys and the current cluster head is labeled as global leader. The intermediate nodes are specified such that the distance to the cluster head and the base station achieve the best fitness scores (Eq. (2)(3)(4)). For future SMO-C versions, we will consider an event-driven sensor activation scenario, where sensors only transmit data if some event occurs, as well as a combination of minimum-transmission-energy (MTE) routing with our fitness-constraint approach in determining the routes.

IV. PERFORMANCE EVALUTION

A. Parameter Settings

We evaluate the performance of our algorithm using MATLAB simulator with P_{CH} = 10% of the nodes being cluster heads. It is assumed that the nodes are distributed randomly in an area of m * m (m^2). The base station is fixed and placed far away from the sensing area. Simulation parameters are listed in TABLE I.

TABLE I
SIMULATION PARAMETER SETTINGS

Parameter	Symbol	Value
Sensing area	m * m	100m x 100m
Base station	(x, y)	(150, 50)
Number of nodes	SN	100
Percentage of cluster heads	P_{CH}	10%
Transmitter electronics	E_{tx}	50 nJ/bit
Receiver electronics	E_{rx}	50 nJ/bit
Transmit Amplifier	E_{fs}	10 pJ/bit/m^2
Transmit Amplifier	E_{amp}	0.0013 pJ/bit/m^2
Data aggregation energy	E_{da}	5 nJ/bit
Initial energy	E_{init}	{0.25, 0.5, 1.0} J/node
Distance threshold	d_0	sqrt(E_{fs}/E_{amp}) m

B. Baseline Protocol

LEACH [17], is low-energy adaptive clustering hierarchy for wireless sensor networks. The LEACH operation divides into rounds. For each round, it consists of two phases,

1) *Set-up Phase [17]:* selection of cluster head using Eq. (9) and cluster formation.

$$T(n) = P_{CH} / (1 - P_{CH} *(r\bmod(P_{CH}^{-1}))) \ , \ \text{if } n \in N$$
$$= 0 \qquad \text{otherwise} \qquad (9)$$

where P_{CH} denotes the user specific percentage of cluster heads, r denotes the number of round in current, and N is the set of nodes that has potential to be elected as cluster heads in the future rounds.

2) *Steady State [17]:* this phase includes data collection data aggregation, and data transmission to the sink. LEACH applies MTE transmission, which performances better than direct transmission to the base station. The transmit route is selected if and only if,

$$E_{amp}(k, d(SN_i, SN_j)) + E_{amp}(k, d(SN_j, SN_t)) < E_{amp}(k, d(SN_i, SN_t)) \qquad (10)$$

$$d(SN_i, SN_j)^2 + d(SN_j, SN_t))^2 < d(SN_i, SN_t))^2 \qquad (11)$$

EAMMH [22] is an energy aware multi-hop multi-path hierarchical protocol for WSNs. In EAMMH, the cluster heads are elected using the initial energy level in order to equalize the magnitude for the energy consumption. Competing with the probabilistic distribution in LEACH protocol, the deployment of cluster heads in EAMMH is more consistent The intra-cluster multi-hop strategy is adapted due to some nodes may consume larger amount of energy through long-distance transmission in terms of data volume and node location [22]. The energy consumed for any cluster member node SN_i to its cluster head SN_{CH} is represented in Eq. (7) and Eq. (8). EAMMH adopts a free space propagation channel model to deliver k-bit packet from node SN_i to another node SN_j, which can communicate with the SN_{CH} as follow [22],

$$E(SN_i, SN_j) = E_{Tx}(k, d(SN_i, SN_j)) + E_{Rx}(k) + E_{Tx}(k, d(SN_j, SN_{CH})) \qquad (12)$$

thus the node with smallest value of energy cost, *E(SN$_i$, SN$_j$)*, will act as the intermediate node. The intra-cluster route is constructed [22],

$$\text{cost}(j) = \omega * \frac{d(SN_i,SN_{CH})^2+d(SN_i,SN_{CH})^2}{\max(d(SN_i,SN_{CH})^2+d(SN_i,SN_{CH})^2)} + (1-\omega) * \frac{E(SN_i,SN_{CH})}{\max(E(SN_i,SN_{CH}))} \quad (13)$$

C. Preliminary Results

In SMO-C, the nodes elect themselves as cluster-head based on the original Spider Monkey Optimization formulation. The associate cluster heads are the ones with best fitness scores and located within the organized local clusters. In addition, SMO-C is a self-organizing, easy to interpret and adaptive clustering protocol. In addition, SMO-C performs local data fusion and minimum energy transmission send data from the clusters to the base station with the optimal route, further enhancing more alive nodes and reducing energy dissipation.

In previous study, the cluster heads in LEACH is unevenly distributed. In some area, there is lack of cluster heads coverage and some of the sensor nodes are placed far away from the cluster heads. To achieve better routes, this situation has been considered in SMO-C. During our selection of cluster heads, we can get better solutions compared with LEACH and EAMMH. Our experimental results show that with better cluster-head locations can obviously increase the nodes lifetime in larger number of rounds and decrease the energy loss of communication. Fig. 3(a)(c)(e) indicates the duration of most nodes is prolonged in SMO-C; it has the lowest number of dead nodes in various initial energy settings. The sensor nodes can last longer when given limited initial energy and prolong the overall network lifetime. It also can be inferred from Fig. 3(b)(d)(f) that the average energy of each node remained in SMO-C is higher than LEACH and EAMMH after immovable iterations. In Spider Monkey social behaviors, monkeys does not maintain fixed size of clusters through their foraging process, which means the percentage of choosing cluster heads (P_{CH}) in routing protocols will not affect the performance in SMO-C. Hence, our experiments carry a specific amount (P_{CH} =10%) of cluster heads.

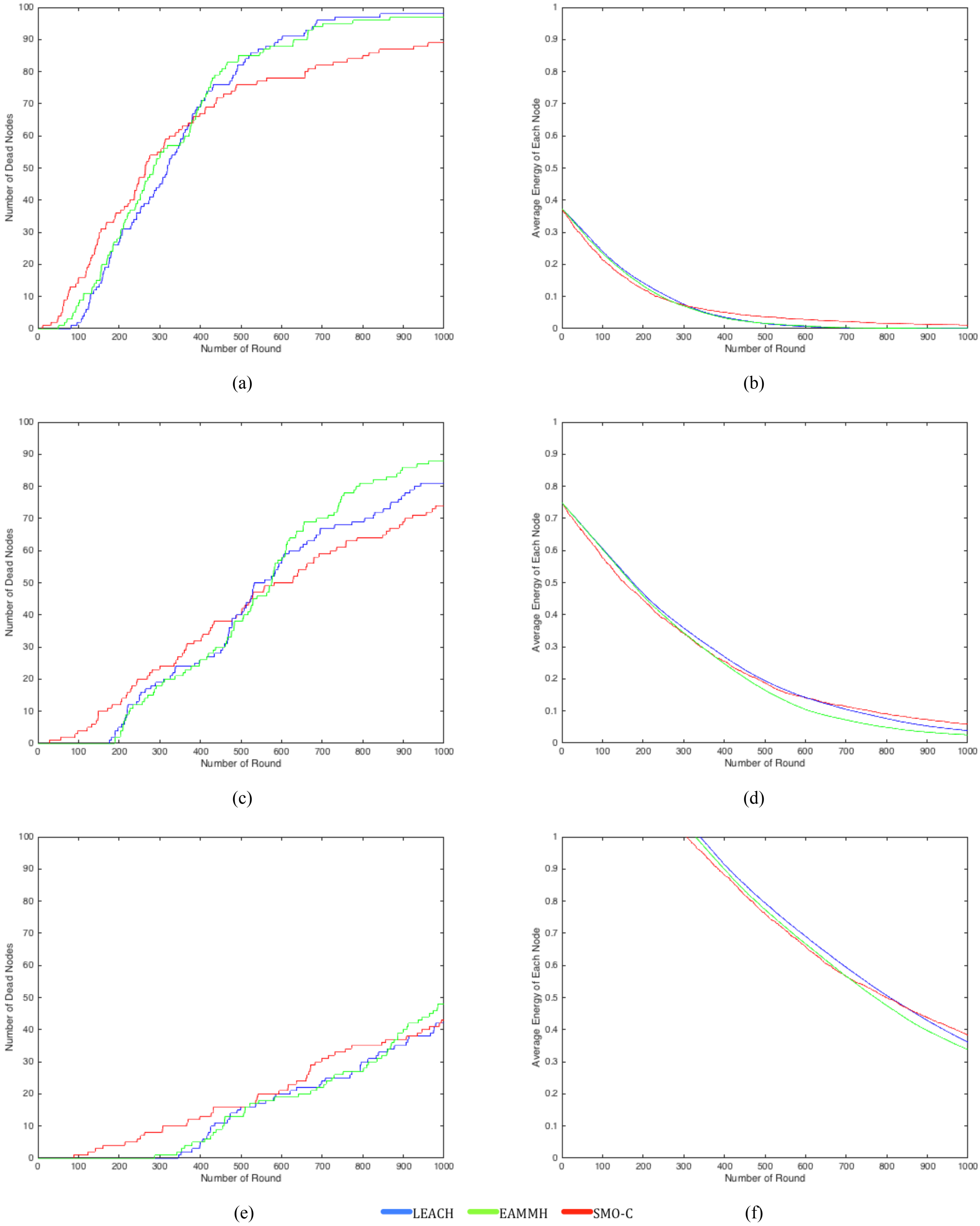

Fig. 3. Performance comparison on LEACH, EAMMH, and SMO-C protocols with different initial energy for the sensors. (***(a)(b)*** *Number of dead nodes and average energy remained after 1000 round with* E_{init} *= 0.25J/node for 100 nodes.* ***(c)(d)*** *Number of dead nodes and average energy remained after 1000 round with* E_{init} *= 0.5J/node for 100 nodes.* ***(e)(f)*** *Number of dead nodes and average energy remained after 1000 round with* E_{init} *= 1J/node for 100 nodes.*)

In the future directions, we can improve SMO-C protocol in terms of time and space complexity, especially in the set-up phase by selecting better locations of cluster heads with minimum energy consumption. Moreover, we can adapt event-driven scenario in data transmission to reduce energy dissipation. Fig. 3(a)(c)(e) shows LEACH and EAMMH takes longer time for the first node to die with different energy threshold, because these two protocols choose initial cluster heads in a randomized manner. Our approach needs further improvements on choosing initial round cluster heads efficiently in order to extend the amount of round for the first dead node and overall network lifetime.

V. CONCLUSION

In this paper, we describe SMO-C protocol that structuring the social foraging behavior of spider monkeys for Wireless Sensor Networks aims to minimize global energy consumption. SMO-C outperforms LEACH and EAMMH approaches by electing the best location cluster heads at a given round and extending the lifetime of surviving nodes. SMO-C is similar to LEACH that self-organizing, no control from the base station, adaptive to topology change and easy to design and interpret. Our experimental results give us an accurate comparison of the pros and cons of the different protocols, LEACH, EAMMH, and SMO-C. We are confident that SMO-C will outperform data-driven routing protocols, with regard to longer life cycle, low energy dissipation, better cluster heads selection and network quality. We hope that the spider monkey optimization based routing strategy will inspire protocol designers to take the neutral and artificial systems into consideration and real time simulations.

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REFERENCES

[1] M. Saleem, G. A. Di Caro, and M. Farooq. "Swarm intelligence based routing protocol for wireless sensor networks: Survey and future directions." Information Sciences 181.20 (2011): 4597-4624.

[2] A. M. Zungeru, L. Ang, and K.P. Seng. "Classical and swarm intelligence based routing protocols for wireless sensor networks: A survey and comparison." Journal of Network and Computer Applications 35.5 (2012): 1508-1536.

[3] Z. Ali, and W. Shahzad. "Analysis of Routing Protocols in AD HOC and Sensor Wireless Networks Based on Swarm Intelligence." International Journal of Networks and Communications 3.1 (2013): 1- 11.

[4] S. Saleh et al., "A survey on energy awareness mechanisms in routing protocols for wireless sensor networks using optimization methods." Transactions on Emerging Telecommunications Technologies 25.12 2014, 1184-1207.

[5] T. Gui, C. Ma, F. Wang and D.E. Wilkins. "Survey On Swarm Intelligence based Routing Protocols for Wireless Sensor Networks: An Extensive Study". In Proceeding to the IEEE International Conference on Industrial Technology (ICIT), 2016.

[6] S. Sendra, L. Parra, J. Lloret and S. Khan, "Systems and algorithms for wireless sensor networks based on animal and natural behavior," nternational Journal of Distributed Sensor Networks, 2014.

[7] M.A. Bharathi, B. P. Vijayakumar, and D. H. Manjaiah, "Cluster based data aggregation in WSN using swarm optimization technique," International Journal of Engineering and Innovative Technology (IJEIT), vol. 2, no. 12, 2013.

[8] S.C. Desai, K. S. Jagadeesh, and K. D. Dhruve, "Enhancing network lifetime in wireless sensor networks adopting elephant swarm optimization," Global Journal of Computer Science and Technology: (E) Network, Web &; Security, vol. 13, no. 4, 2013.

[9] M.A. Bharathi, B. P. Vijayakumar, and M. Mallikarjuna, "A novel approach for energy effecient data aggregation using elephant behavior as a swarm intelligence," Lecture Notes on Software Engineering, vol. 1, no. 2, pp. 153-155, 2013.

[10] K. Benahmed, M. Merabti, and H. Haffaf, "Inspired Social Spider Behavior for Secure Wireless Sensor Networks," International Journal of Mobile Computing and Multimedia Communications, v.4 n.4, p.1-10, 2012.

[11] A.M. Zungeru, Li-Minn Ang, and Kah Phooi Seng. "Termite-hill: Performance optimized swarm intelligence based routing algorithm for wireless sensor networks." Journal of Network and Computer Applications 35.6 (2012): 1901-1917.

[12] S. Kumar, Rajani Kumari, and Vivek Kumar Sharma. "Fitness Based Position Update in Spider Monkey Optimization Algorithm." *Procedia Computer Science* 62 (2015): 442-449.

[13] A. Al-Azza, Ammar Al-Jodah, and Frances Harackiewicz. "Spider Monkey Optimization: A Novel Technique for Antenna Optimization." IEEE Antennas and Wireless Propagation Letters, VOL. 15, 2016.

[14] S.E. Kumar, and S.M. Kusuma. "Clustering protocol for wireless sensor networks based on Rhesus Macaque (Macaca mulatta) animal's social behavior." International Journal of Computer Applications 87.8 (2014).

[15] D. Karaboga, An idea based on honey bee swarm for numerical optimization. Vol. 200. Technical report-tr06, Erciyes University, engineering faculty, computer engineering department, 2005.

[16] J. Fleagle, Gilbert, C. Rowe, N.; Myers, M., eds. "Primate Evolution: John Fleagle and Chris Gilbert". All the World's Primates. Primate Conservation, Inc. Retrieved 18 December 2014.

[17] W. Heinzelman, Chandrakasan, A., and Balakrishnan, H., "Energy-Efficient Communication Protocols for Wireless Microsensor Networks", Proceedings of the 33rd Hawaaian International Conference on Systems Science (HICSS), January 2000.

[18] J.C. Bansal, et al. "Spider monkey optimization algorithm for numerical optimization." *Memetic computing* 6.1 (2014): 31-47.

[19] K. Akkaya, and M. Younis. "A survey on routing protocols for wirelss sensor networks." Ad hoc networks 3.3 (2005): 325-349.

[20] R.C. Eberhart, and J. Kennedy. "A new optimizer using particle swarm theory." Proceedings of the sixth international symposium on micro machine and human science. Vol. 1. 1995.

[21] S. Das et al. "Bacterial foraging optimization algorithm: theoretical foundations, analysis, and applications." Foundations of Computational Intelligence Volume 3. Springer Berlin Heidelberg, 2009. 23-55.

[22] M.R. Mundada, V CyrilRaj and T Bhuvaneswari "Energy Aware Multi-Hop Multi-Path Hierarchical (EAMMH) Routing Protocol for Wireless Sensor Networks" European Journal Of Scientific Research ISSN 1450-216X Vol. 88 No 4 October, 2012