Periodicals of Engineering and Natural Sciences ISSN 2303-4521
Vol. 7, No. 1, June 2019, pp.82-98
Available online at: http://pen.ius.edu.ba

Effective data routing using mobile sinks in disjoint mobile wireless sensor networks

Hager Ramadan [1], Ahmed M. Khedr[2], Dharma P. Agrawal[3]
[1,2]Mathematics Department, Faculty of Science, Zagazig University, Zagazig, Egypt
E.mail:{amkhedr,hramadan}@zu.edu.eg
[2]Computer Science Dept., Faculty of Sciences, University of Sharjah, Sharjah 27272, UAE
E-mail: akhedr@sharjah.ac.ae

[3]EECS, University of Cincinnati, Cincinnati, OH 45221-0030

Article Info

Received Oct 12, 2018

Keyword:

Cluster based Mobile Wireless Sensor network
Disjoint cluster
Energy-aware routing
Mobile and Static sinks
Network lifetime

ABSTRACT

In Mobile WSNs (MWSNs) , disjoint clusters could be naturally formed in an unpredictable way that possess the nature of highly dynamic connected and disconnected schema. Many partitions of the network could happen in disjoint mobile wireless sensor networks (DMWSNs), and could last for a significant amount of time that can challenge current routing protocols in crisis-driven and geography-driven applications. We propose in this paper, two new centralized and distributed routing discovery protocols for DMWSN. In the centralized protocol, the static sink controls the motion of mobile sinks. In the distributed protocol, each mobile sink is responsible for collecting data in a specific region. In our work, the mobile sinks need to coordinate among themselves for communication with the base station (BS). The simulation results shows the advantage of our newly proposed protocols in terms of time delay, energy consumed, and the delivery ratio.

Corresponding Author:

Ahmed M. Khedr,

Computer Science Dept., Faculty of Sciences,University of Sharjah, Sharjah 27272, UAE
E-mail: akhedr@sharjah.ac.ae
Mathematics Department, Faculty of Science, Zagazig University, Zagazig, Egypt
E.mail: amkhedr@zu.edu.eg

1. Introduction

Recent advances in WSNs have attracted much interest and have remarkable influence on the efficiency and performance of a variety of applications such as disaster management and surveillance. Such systems are able to process data collected from multiple sensor nodes to monitor activities and events in the observation area [1–3, 34-44]. Due to presence of wind and obstacles, the actual landing positions of sensors cannot be controlled. As a result, the coverage may be marginal as compared to the requirements of application and could remain true no matter the count of deployed WSN nodes. Therefore, it is required to make use of mobile nodes that are capable to move to required positions so as to ensure the desired area coverage [4–6]. Consequently, the design of related algorithms or protocols is highly challenging in such a distributed environment. Moreover, the sensor nodes suffers from many limitations, such as limited power source, short communication radius and small storage. These restrictions also make the design of WSN protocols challenging.

A MWSN is comprised of a collection of mobile sensors with self-organizing and cooperative capability to detect and predict objects of interest [7, 8]. All properties of MWSNs inherit from static WSNs and they possess their own unique property of mobility. The nodes in these networks collaboratively sense and collects data from different regions of the monitored area and provides a global sketch of monitored events and activities. However, a WSN node failure can imply connectivity loss, which in turn leads to partitioning of the WSN. Adding mobility to WSN nodes can appreciably enhance the potential of the WSN by making it reactive to events, resilient to failures and to support diverse set of applications with a common set of sensors. Collecting and routing sensed data from the sensor nodes is an essential concern in WSNs due to limited power of WSN nodes which are usually deployed randomly as WSN inside the region of interest. Using mobile nodes in data gathering process after a assistance in monitoring larger region and transmitting data to unreachable BS. A remote BS is deployed to gather data captured by the WSN nodes. Sensor nodes communicate with the BS through multi-hop, which may be feasible in the case of disjoint clusters. To develop an efficient protocol for data gathering with existing holes is an on-going research and is the core of this paper.

Most of the existing routing protocols are proposed to handle dense and sparse networks. However, not much work has been proposed to handle the situations where the MWSNs is divided into a set of partitions and lasting for a significant period of time. The current routing protocols cannot handle such situation. The routing challenges for disjoint clusters of WSNs without having global information about dynamically created clusters is discussed in this paper. Each disjoint cluster needs to find a path to BS so as to deliver collected data and cluster information to BS. We propose two new distributed and centralized routing discovery protocols. In the centralized protocol, the static sink controls the motion of mobile sinks; while in distributed scheme, each mobile sink is responsible for collecting data in a given specific region. The mobile sinks need to coordinate globally among themselves so as to maintain the original network topology as much as possible and make global knowledge.

The remainder of this work will be as: The relvent work will be illustrated in Section 2. Section 3 presents a description of relevant terms. Section 4 explains the proposed protocols. Section 5 includes the evaluation of the proposed protocols and compares the results with the existing protocols. The conclusion of our work is given in Section 6.

2. Related Work

WSN routing is challenging and difficult due to various features that differentiate WSNs from contemporary Wireless Adhoc Networks [15, 16, 19] such as: (1) It is not feasible to apply Classical IP-based approaches to WSNs , as it is not possible to create a global addressing scheme because of sheer count of WSN nodes, (2) In contrast to existing communication networks, most of the WSN applications demand the flow of data sensed from various areas to a specific sink; (3) significant redundancy exists in the data traffic generated, because multiple WSN nodes may produce the same data within the neighborhood of an activity under monitoring. In order to improve bandwidth utilization and energy, routing protocols are required to exploit such redundancy, (4) The WSN nodes are highly constrained in terms of resources like energy, capacity for processing and transmission power and therefore needs effective management of resources. Thus, several protocols are proposed for solving data routing problem. Together with the application and architecture necessities, such routing protocols have included the features and demands of WSN nodes.

Existing WSN data routing protocols are categorized as Location based, Hierarchical Data-centric and a few distinct protocols according to QoS or network flow demands. The protocols in Data-centric class are often query-based and in contrast to traditional address based routing, it is based on naming of intended data based on application needs, that helps to eliminate various transmission redundancies [9, 11, 17, 18, 23]. In Hierarchical protocols, the sensor nodes are grouped into a set of clusters, and one node is elected from each cluster as a cluster head (CH) and the remaining sensors are cluster members (CMs). CH can do aggregation to reduce data and save energy [12, 14, 38-44]. Location-based protocols utilize location details to send the data to required areas instead of the whole WSN [22]. The last type of routing techniques include protocols that depends on network-flow and that aims to satisfy the QoS needs in conjunction with the routing operation[10]. All these protocols work well in connected network, where the path from the sensor nodes to others or the BS can be determined. However, in our work, the network consists of disjoint clusters where the path between each two clusters and between a CH and the BS cannot be established. In [31], a grouping scheme is proposed such that the nodes are partitioned into various groups, where the nodes that belongs to a particular group are relatively close to each other based on geographical information. This method of grouping performs cluster-based routing based on grouping CHs scheme and therefore enhance scalability, decreases energy utilization, and extends the lifetime of WSN. Such protocols cannot exchange messages if the CHs cannot find another CH within its communication range or clusters are disjoint. It is highly challenging to find an optimal WSN deployment strategy that can reduce cost and computation, minimizing communication overhead, offering high degree of coverage and connectivity and resilient to node failures. The network could become disjoint at any time. WSN cannot serve its application well. To work in this case, some techniques must be utilized. In [24], a message ferrying (MF) technique is deployed, that works well for sparse networks. MF is a proactive method that exploits mobility. It employs a special set of mobile sensors as message ferries (MF or ferries) that facilitate the required services for communication between sensor nodes, and are in charge for data gathering in sparse WSNs. The major purpose of MF approach is to instigate non-random sensor movements and to utilize such movements to facilitate efficient data collection and delivery.

[25] Proposed, in hybrid WSN, a three-phase efficiently heuristic scheduling method of mobile sink. The WSN is split into grids and these grids are categorized into clusters. This approach produces optimal grid cell division for the network which prolongs the WSN lifetime. For energy balancing inside clusters, the clusters arrange themselves by allocating or deallocating grid cells. An inter-cluster based on ACO algorithm was proposed in [26] for data packet routing in WSN. The algorithm uses NLEACH when inter-cluster ACO aggregate data. This method reduces energy consumption in transferring unnecessary data sent by sensors. In [27] the Mode Switched Grid-based Routing (MSGR) protocol is proposed which uses the benefits of grid-based protocols. Each grid head nodes switches between active and sleep modes. The grid head nodes that are put on sleep mode are those which are not taking part in the routing.

In [28], a polynomial time heuristic approach is introduced, called Relay Placement algorithm based on Space Network Coding (RPSNC) which finds the optimal locations of relay sensor nodes, to find solution to the problem of network connectivity restoration and aims to reduce the count of relay sensor nodes needed for connectivity restoration in huge networks using non-uniform partitioning, Delaunay triangulation and linear programming (LP) techniques. The authors in [29] proposed the method which adds long distance routing nodes to the WSN to improve the network connectivity during the growth of plants. The connection rank matrix is used to represnt the connectivity of the deployed WSN based on the graph theory. A fully connected network is marked by the rank with value of 1. The smaller value of rank means the better connectedness.

In a given MWSN, the authors of [30] investigate the issue of data gathering, in which multiple MS focus to gather data from a provided collection of static sensor nodes. This work proposes a Co-operative Data Collection Algorithm (CDCA) that divides the sensors as groups with local mobile sink to gather the generated data by the nodes in each group of sensors. The CDCA constructs a global path for gathering data from the local mobile-sinks to the global mobile-sink after selecting a set of data gathering points in each group and constructing a separate path covering every data gathering point in each group.

In [13], two routing protocols are introduced, first one is utilizes straight line messengers moving (SLMM) and the second utilizes flexible sharing policy of messengers (FSPM). In SLMM, once a WSN node in a cluster gets the request from the CH, it communicates with the neighbor nodes, and moves out of the cluster in the direction of BS. When it reaches BS, it interchange its data with BS. BS gives information of other existing clusters to the messenger. It then takes the data and back to its initial cluster. After iterating this scenario with different clusters, all the cluster information is shared among themselves. The packet structure for FSPM is same as that of SLMM protocol. In [32], the authors added a higher tier genetic fuzzy system to SLMM and FSPM for route discovery and maintenance. They proposed two routing protocols: (1) Genetic Fuzzy Straight Line Moving of Messengers (GFSLMM) and (2) Genetic Fuzzy Flexible Sharing Policy of Messengers (GFFSPM). The main distinction between our proposed protocols and the work in [13, 32] are the following: (1) In [13, 32], there is only one static sink which causes a large long movement of the messengers. However, in our work, we introduce mobile sinks that move to the cluster of request to pick the sensing data directly from the clusters. In [13, 32], the messengers takes the sensed data packet and move to the BS to unload the data. This process is repeated by the messenger till the target moves away from the cluster. By this way, the messenger exhausts its battery quickly and causes additional partitioning of the network so as to save energy of the messengers. In our work, the messenger moves to the BS only one time to inform its cluster's location that makes mobile sink to move to that location. The mobile sink leaves this location as the target moves to another cluster. Here, the messengers moves to the new location of the mobile sink, decreasing the movement's distance. The messenger shares cluster information with the messengers from other clusters or with intermediate clusters it passes by. In [13, 32], the messengers have the responsibility to move to the BS to route the data. However, in our work, the mobile sinks have the responsibility to route the data.

3. Mobile Sinks Based Routing Protocols

In DMWSN, there exist relatively stable network partitions and every partition of the network has a connected dominated set (CDS) [33]. In this paper, we consider how to solve the problem of routing data from disconnected clusters effectively. In the following subsections, we introduce a description of some relevant terms that will be used in our proposed protocols.

Cluster Based Organization: In the cluster-based partitioned network, sensors functions are clas- sified as general sensor, CH, sink node and messenger. In each cluster, we employ Dynamic Source Routing protocol (DSR).

In this paper, any appropriate clustering algorithm can be used, and we are not concerned with the details of the clustering algorithms. Our proposed protocols do not impose any specific restrictions or requirements on the choice of the clustering algorithm.

Following are the assumptions we have in developing the routing protocols for the DMWSN.

Localization information exists in the network [20].

Each sink has the information of all mobile sinks in the network and it can communicate with any one of them directly or via other sinks.

The mobile sinks are static if there is no any demand from either static sink or messenger.

The transmission range is a disc-unit with the value r to the sensor nodes and R to the sinks in which R > r.

3.1. Centralized Mobile Sinks Routing Protocol

In centralized mobile sinks routing protocol, every CH selects a messenger as a sensor with highest energy. To reduce the consumed energy in messenger moving, condition 1 below and conditions 2 or 3 must be satisfied before CH assigns a messenger.

1. Cached pipeline is full.
2. The time of wait is greater than the minimum defined waiting time, before sending the messenger.
3. The time of wait is greater than the maximum defined waiting time, before resending the messenger.

Before appointing a messenger, condition 1 assures that enough information has been collected. Condition 2 assurances the proper time for sending a messenger. Condition 3 indicates that for sharing cluster information the cluster resumes sending out next messenger if the previous messenger expires after a long time.

In this protocol, the network consists of sensor nodes, BS, and mobile sinks. Node moves out of the cluster in the direction of BS, when it receives a request of messages from the CH using multiple hops.

It exchanges carried data with BS. The BS provides the messenger with the clusters information and the new location of the mobile sink to send the information so that when the second time the messenger carries the data, it returns to its actual cluster. The process is iterated in different clusters, and the linear time is the total cost of sharing all clusters information. Figure 1 shows the process.

The BS demands the nearest mobile sink to move to the location of the target cluster if there is no mobile sink in the range of the cluster. The movement of the mobile sink must occur without any destruction of connections of the sinks. The new location (x_n, y_n) of the moved mobile sink is computed as follows:

$$\Theta = \arctan\left[\frac{y_c - y_s}{x_c - x_s}\right] \quad (1)$$

$$x_n = x_s + R\cos\Theta, \quad (2)$$

$$y_n = y_s + R\sin\Theta, \quad (3)$$

Here, (x_c, y_c) denotes the target's cluster and (x_s, y_s) denotes the second mobile sink location that is the nearest to the target's cluster. The mobile sink has three states: power-off, power-on, and processing. If the mobile sink in the processing state or play a role in keeping connections between sinks is demanded by the BS to move, the location of the sink is replaced by cascading mobile sinks of the route path [21].

.

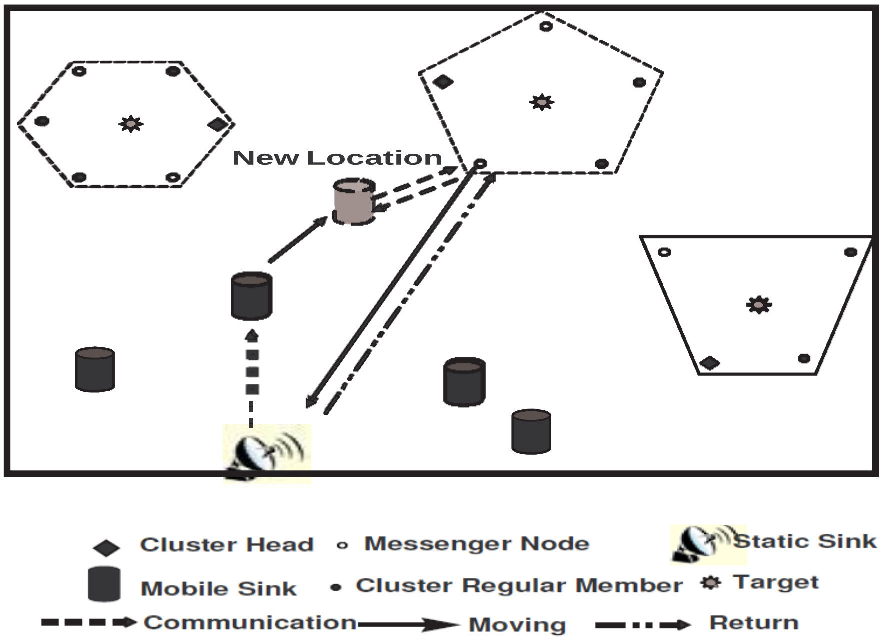

Figure 1: Planar diagram of the Process

3.1.1. The Protocol Outline

Step 1 Sensory data is collected from members and is stored in the pipeline memory by the CH. CH elects the sensor node with maximum energy as a messenger if the cached pipeline is full. Start step 2 if condition 2 or 3 above is satisfied.

Step 2 Using DSR, Cluster Set Information is generated and routed by CH to the chosen messenger. The command type and trigger time is shown by messenger. The messenger starts step 3 if the command type is 0.

Step 3 Messenger that have information packet proceeds out cluster and goes in the direction of BS. At every r/v time, a probing message is broadcasted by the messenger, and it waits for answering. In its way, if any mobile sink replies to BS, the messenger exchanges its carrying packet with BS through that mobile sink directly or via another mobile sinks. In Step 4, the messenger waits to get the reply from the BS via the sink. If the messenger received reply from a mobile sink, it enters step 6. However, the mobile sink tranmits the cluster details in its communication cycle. The track information is saved by the moving messenger for next delivery. The cluster set information packet includes the cluster's own details and details of other clusters obtained from the previous messengers (global knowledge).

Step 4 The messenger unloads its carrying packet at the BS. BS reveals the information, and adds/updates the cluster information. Then, it provides the messenger's cluster with the nearest mobile sink. The BS routes the message to the mobile sink using routing solution as in step 2.

Step 5 The selected mobile sink receives the message from the BS and moves to the nearest point to the cluster without breaking the connections to other sinks.

Step 6 The new packet is carried by the messenger and it goes back to its cluster.

Step 7 When the messenger contacts any one of its cluster members, it unloads the message packet from BS. The packet is routed to the CH as in step 2 as per the process is shown in Figure 1.

3.2. Distributed Mobile Sinks Routing Protocol

This protocol works on the network where all sinks are mobile. This structure is based on straight line mobility of the messenger. The key difference between this protocol and the previous one is that each sink is responsible for gathering data from a specified region (its authority region). The mobile sink can communicate with all sensors in its region. The regions of the mobile sinks are overlapped so the sink can communicate and exchange data with its neighbor sinks by moving the sinks to an overlapped region within a delay time (the time that every two adjacent sinks accepted to exchange data between them) to exchange the information. If there are more than one cluster requests for a particular mobile sink, the mobile sink moves to the location of center of gravity (COG) or centroid which is the average of X ,Y coordinates of the cluster locations.

3.2.1. The Protocol Outline

Step 1 Collected data is stored in the the pipeline memory of the CH. If pipeline is full cached the CH selects the messenger as the node with maximum energy. If condition 1 or 2 are satisfied, it starts step 2.

Step 2 Using DSR, the selected messenger obtains the Cluster Set Information Packet from the CH. The command type and trigger time messenger are retrieved by the messenger. If zero command type, then the messenger starts step 3 after the trigger time;

Step 3 At every r/v time, messenger with information packet time broadcasts a probing message, and if it receives a reply from an other cluster, it shares with the cluster its packet. It shares information with the mobile sink as well. After this process, it starts step 5. The mobile sink broadcasts cluster information in its communication cycle. The moving messenger saves the track information.

Step 4 At the BS, the messenger unloads its packet. The mobile sink updates or adds the current cluster information and sends its new location.

Step 5 The messenger is returned a new packet back to its cluster.

Step 6 The messenger unloads its packet to regular member of its cluster when they meet, it is routed to its CH. The process is illustrated in Figure 3.

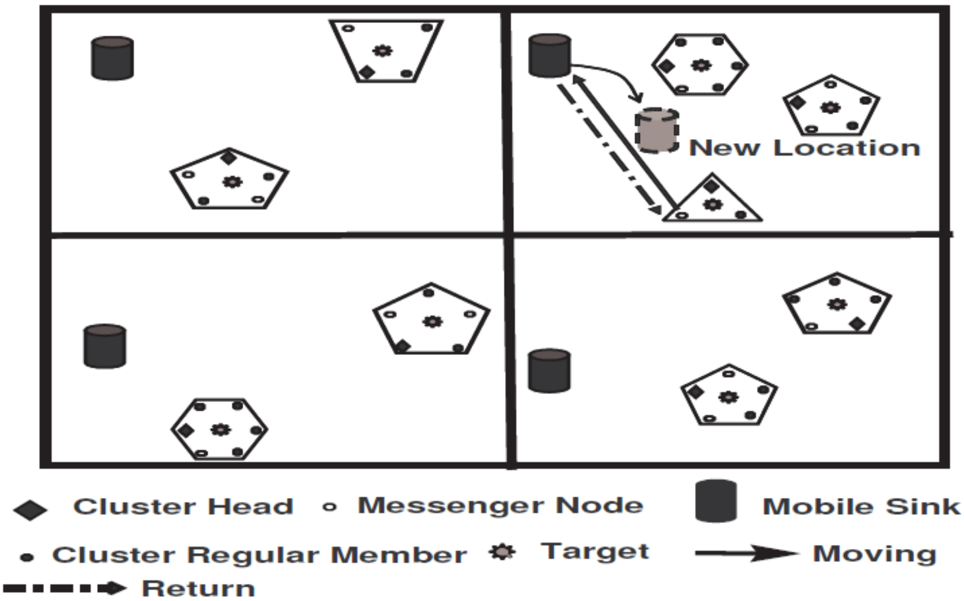

Figure 2: Planar diagram of the Process

4. Simulation Results

We provide the results of simulation in this section to show the performance and illustrates the benefits of the two proposed protocols and to compare the energy consumption, count of live nodes, packet delivery ratio and end to end delay of our proposed protocols (CMSR and DMSR) and existing protocols.

Simulation Environment: The simulation uses the same environment that used in [13], where ten disjoint targets are deployed randomly in 800 $m \times 640$ m area. In our preliminary experiments 100 WSN nodes are randomly roaming to detect targets initially. The radio propagation range of each sensor is 50 m, the radio propagation range of each sink is 200 m, the speed of moving of the sensors and the sinks is 2 m/s and the number of the mobile sinks is 10.

Performance Metrics: The following are the performance metrices used in this simulation.

1. Consumed energy: The consumed energy as the total energy consumed during transmission, reception, and motion.
2. Average end-to-end delay: obtained by averaging the end-to-end-delay over all existing data packets from the sensor source to the BS.
3. Packet Delivery Ratio: The ratio of the total count of successfully received packets successfully to the total count of transmitted packets.

We illustrates the results of our simuation in terms of the energy consumption and the count of nodes alive curves with the number of rounds, end to end delay with the average degree, and packet delivery ratio with the time spent. A round can be represented as the time required for transferring one packet from the node in target's cluster to the BS. The battery capacity limitation is a challenging concern in designing mobile sensor networks. We represent the networks energy consumption as EC. It is an important issue to conserve energy while finding the network route. Energy for sensors and sinks are mostly consumed during transmission and movement. The moving activities of the sensors include the roaming and the messaging of messenger in the first step. The moving activities of the sinks include the movements of the mobile sinks to the target's cluster location to get the data and the movements for data exchange and update.

The transmission energy utilization of the sensors occurs when the normal nodes in a cluster upload messages or data, CH assigns a sensor as the messenger and the messengers exchange data between each other and in the case of the sink the transmission energy consumption occurs when data or messages is uploaded, and when the data is exchanged between each other. In our work, a linear formula of EC' is defined according to the activities as:

$$EC' = EC_1 + EC_2. \tag{4}$$

$$EC_1 = W_m(R_o + M_g) + W_t(D_{up} + D_{ex} + D_{am}), \tag{5}$$

$$EC_2 = W_m M_g + W_t(D_{up} + D_{ex}), \tag{6}$$

where EC1 denotes the energy consumed by the sensor nodes in the first step that basically informs the sink the location of the target's cluster), EC2 is the energy consumed by the mobile sinks, Wt denotes the weight of a transmission activity, Wm denotes the weight of a moving activity, Dup represents the amount of updated packets, Ro denotes the steps of roaming activity, Mg represents the steps of messaging activity, Dex is the amount of exchanged packets, and Dam is the set of appointing messenger times.

The experimental results shown in Figure 3 shows that DMSR protocol for route discovery is more energy efficient and consistent than CMSR. This is because assigning sink for each region to be responsible for exchanging and gathering data reduces the movements required and so the energy consumption. Figure 3 also shows that DMSR and CMSR is more energy efficient than FSPM, SLMM, and GFFSPM. This is because FSPM, SLMM, and GFFSPM have static BS, so the movements of the messengers are performed to a fixed location that cause a negative influence on energy consumption. This is not the case in DMSR or CMSR where the mobile sink moves to the cluster that requests data exchange and delivery of data among the sinks. The mobile sink stays in the cluster to collect the data as the target exists. The transmission data packets is executed by the mobile sinks not via the messengers (sensor nodes) which can increase the lifetime of the network. In addition, mobile sinks collect the sensed data from other clusters in this way to the cluster of request that saves more energy of the messengers. On the other side, FSPM is more energy efficient than SLMM because in FSPM, a messenger exchanges cluster information with messengers from other clusters or with intermediate clusters it passes by , while in SLMM, the messengers have to move to a fixed location of the static sink to exchange data and return to its clusters. GFFSPM shows better energy consumption than FSPM. But, due to limited number of clusters in our experiment, the population space is not large enough to make use of genetic algorithm efficiently.

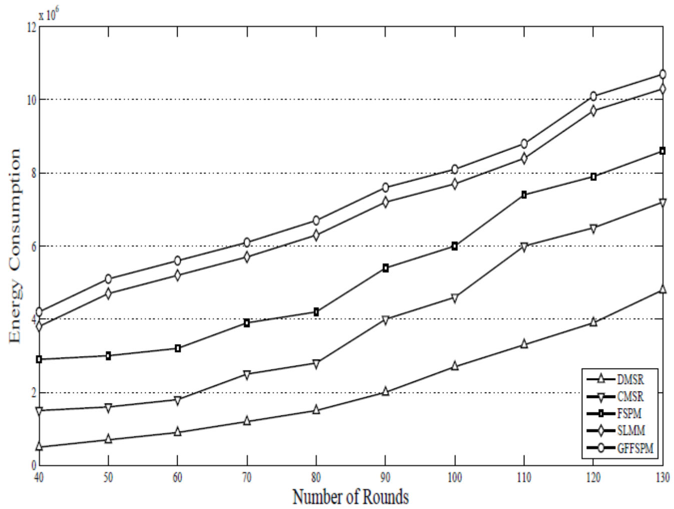

Figure 3: Energy Consumption Comparison between the proposed and existing Routing Discovery Protocols

Figure 4 depicts the effect of using mobile sinks on the number of active nodes of our proposed protocols and existing protocols. It shows that using mobile sinks in our proposed protocols has a great impact on increasing the number of the active nodes as compared with FSPM, SLMM, and GFFSPM protocols. This is because all the data delivery is performed by the sensor nodes in FSPM, SLMM, and GFFSPM, however, in our proposed protocols every messenger moves to the static sink at most only one time to submit its cluster information. Then, the messengers move to the nearest sink in the next time which decreases the consumed energy of the messengers.

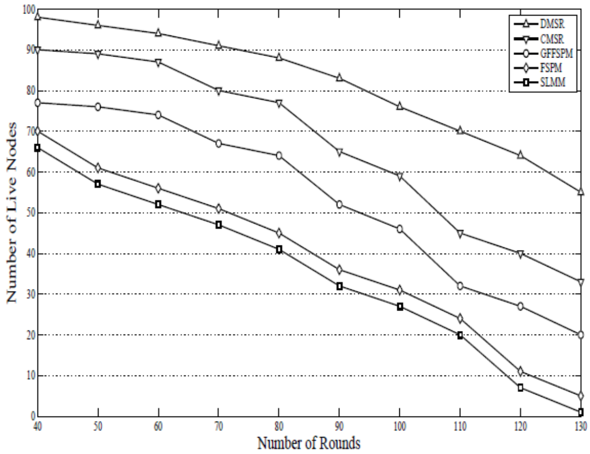

Figure 4: Active nodes in our proposed and existing Routing Discovery Protocols

Figures 5 and 6 shows end to end delay and packet delivery ratio of our proposed protocol in comparison with the existing protocols. As shown in the figures, end to end delay and the packet delivery ratio increases as the average degree increases. End to end delay of our proposed protocols is better than of existing protocols (FSPM, SLMM, and GFFSPM) as the use of mobile sinks in our proposed protocols reduces the movement distances inside the network while existing protocols use static sinks. Also, reducing the movement distances improves the packet-delivery ratio as shown in and Figure 5 and the packet-delivery ratio increases as the time spent increases.

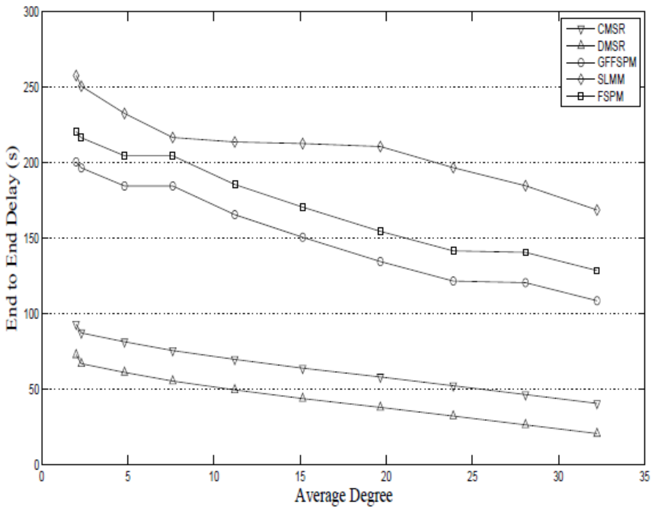

Figure 5: End to End Delay in our proposed and existing Routing Discovery Protocols

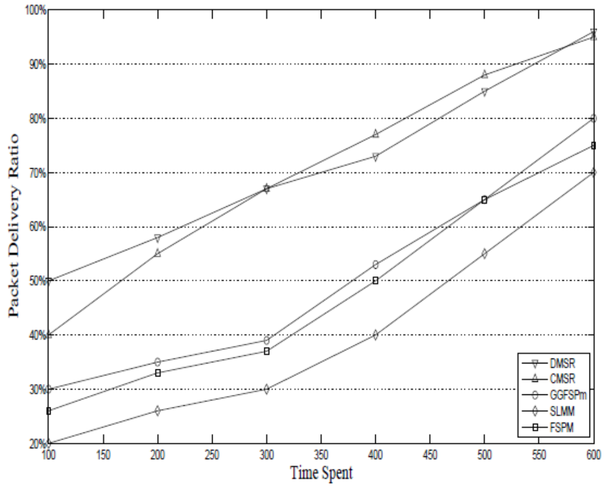

Figure 6: Packet Delivery Ratio in our proposed and existing Routing Discovery Protocols

6. Conclusion

From the simulation outputs, we can conclude that our proposed routing protocols provide more energy savings than the existing protocols. Therefore, our protocols not only enhance the network lifetime but also minimizes the end to end delay and increase the packet delivery ratio. The cooperative efforts of cluster knowledge sharing and collaboration among autonomous agents in carrying out autonomous terrain monitoring and communication with the BS for prolonging network lifetime.

References

[1] Salim A., Walid Osamy and Khedr A. M., Effective Scheduling Strategy in Wireless Mul- timedia Sensor Networks for Critical Surveillance Applications, Appl. Math. Inf. Sci. 12, No. 1, 101-111 (2018).

[2] Khedr A. M. and Walid Osamy, Effective Target Tracking Mechanism in a Self-Organizing Wireless Sensor Network, Journal of Parallel and Distributed Computing, Vol. 71, pp. 1318-1326, 2011.

[3] Khedr A. M. and Walid Osamy, Nonlinear Trajectory Discovery of a Moving Target by a Wire- less Sensor Network, Journal of Computing and Informatics, Vol. 29, No. 5, pp. 1001-1016, 2010.

[4] Khalifa B., Zaher Al Aghbari, Ahmed M. Khedr, Jemal Abawajy, Coverage Hole Repair in WSNs Using Cascaded Neighbor Intervention, IEEE SENSORS JOURNAL, VOL. 17, NO. 21, pp. 7209-7216, NOVEMBER 1, 2017.

[5] Khedr A. M., Walid Osamyb, Ahmed Salim, Distributed coverage hole detection and recovery scheme for heterogeneous wireless sensor networks, Volume 124, June 2018, Pages 61-75.

[6] Khedr A. M. and Walid Osamy, Minimum perimeter coverage of query regions in heteroge- neous wireless sensor networks, Information Sciences, Vol. 181, pp. 3130-3142, 2011.

[7] Khedr A. M., New Mechanism for Tracking a Mobile Target using Grid Sensor Networks, Computing and Informatics, Vol. 28, pp.1001-1021, 2008.

[8] Khedr A. M. and Walid Osamy, Tracking Mobile Targets using Random Sensor Networks, The Arabian Journal for Science and Engineering, Vol. 32, No. 2B, pp. 301-315, October 2007.

[9] Braginsky D. and Estrin D. "Rumor routing algorithm for sensor networks," in Proceedings of the First Workshop on Sensor Networks and Applications (WSNA), Atlanta, GA, October 2002.

[10] Chang J-H and Tassiulas L., "Maximum Lifetime Routing in Wireless Sensor Networks," in Proceedings of the Advanced Telecommunications and Information Distribution Research Program (ATIRP2000), College Park, MD, March 2000.

[11] Chu M., Haussecker H., and Zhao F., "Scalable Information Driven Sensor Querying and Rout- ing for Ad Hoc Heterogeneous Sensor Networks," the International Journal of High Performance Computing Applications Vol. 16, No. 3, pp. 293-313, 2002.

[12] Heinzelman W., Chandrakasan A., and Balakrishnan H., "Energy-efficient Communication Protocol for Wireless Sensor Networks," in Proceeding of the Hawaii International Conference System Sciences, Hawaii, January 2000.

[13] Hundewale N., Cheng Q., Hu X., Bourgeois A., and Zelikovsky A., "Autonomous Messen- ger Based Routing in Disjoint Clusters of Mobile Sensor Networks," Agent Directed Simulation ADS1706 (in SCS2006), 2006.

[14] Manjeshwar A. and Agrawal D.P., "APTEEN: a Hybrid Protocol for Efficient Routing and Comprehensive Information Retrieval in Wireless Sensor Networks," in Proceedings of the 2nd International Workshop on Parallel and Distributed Computing Issues in Wireless Networks and Mobile computing, Ft. Lauderdale, FL, April 2002.

[15] Ok C., Lee S., Mitra P., and Kumara S., "Distributed routing in wireless sensor networks using energy welfare metric," Information Sciences, Vol. 180, No. 9, pp. 1656-1670, 2010.

[16] Saleem M., Di-Caro G. A., and Farooq M., "Swarm Intelligence based Routing Protocol for Wireless Sensor Networks: Survey and Future Directions," Information Sciences, In Press, Corrected Proof, Available online (doi:10.1016/j.ins.2010.07.005) 23 July 2010.

[17] Schurgers C. and Srivastava M. B., "Energy efficient routing in wireless sensor networks," in the MILCOM Proceedings on Communications for Network-Centric Operations, Creating the Information Force, McLean, VA, 2001.

[18] Shah R. and Rabaey J., “Energy Aware Routing for Low Energy ad hoc Sensor Networks,” in Proceedings of the IEEE Wireless Communications and Networking Conference (WCNC), Orlando, FL, March 2002.

[19] Srgio S. P., Aurlio S. S., and Perkusich A., “Broadcast Routing in Wireless Sensor Networks with Dynamic Power Management and Multi-coverage Backbones,” Information Sciences, Vol. 180, No. 5, pp. 653-663, 2010.

[20] Tilak S., Kolar V., Abu-Ghazaleh N. B., and Kang K-D, “Dynamic Localization Protocols for Mobile Sensor Networks,” IEEE IWSEEASN 2005.

[21] Wang G., Cao G., Porta T. L., and Zhang W., “Sensor Relocation in Mobile Sensor Networks,” In Proc. of IEEE INFOCOM, pp. 2302-2312, 2005.

[22] Xu Y., Heidemann J., and Estrin D., “Geography-informed Energy Conservation for ad hoc Routing,” in Proceedings of the 7th Annual ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom01), Rome, Italy, July 2001.

[23] Yao Y. and Gehrke J., “The Cougar Approach to in-network Query Processing in Sensor Networks,” in SIGMOD Record, September 2002.

[24] Zhao W., Ammar M., and Zegura E., “A Message Ferrying Approach for Data Delivery in Sparse Mobile Ad Hoc Networks,” Proceedings of ACM Mobihoc, 2004.

[25] Zhou Z., C. Du, L. Shu, G. Hancke, J. Niu and H. Ning, ”An Energy-Balanced Heuristic for Mobile Sink Scheduling in Hybrid WSNs,” in IEEE Transactions on Industrial Informatics, vol. 12, no. 1, pp. 28-40, Feb. 2016.

[26] M.Thakur, ”Mobile Sink Based NLEACH Protocol by using Ant Colony Optimization,” International Journal of Science Research and Technology, vol. 2, Issue 1, pp. 1-10, 2016.

[27] S. Sharma, D. Puthal, S. Tazeen, M. Prasad and A. Y. Zomaya, ”MSGR: A Mode-Switched Grid-Based Sustainable Routing Protocol for Wireless Sensor Networks,” in IEEE Access, vol. 5, pp. 19864-19875, 2017.

[28] A. Uwitonze , J. Huang, Y. Ye and W. Cheng,”Connectivity Restoration in Wireless Sensor Networks via Space Network Coding,” Sensors, 17, 902, pp. 1-21, 2017.

[29] Chen Y, Shi Y L, Wang Z Y, Huang L.,” Connectivity of wireless sensor networks for plant growth in greenhouse,” Int J Agric and Biol Eng, 9(1), pp. 89-98, 2016.

[30] W. Wen,1 C. Y. Chang, S. Zhao, and C. Shang, ”Cooperative Data Collection Mechanism Using Multiple Mobile Sinks in Wireless Sensor Networks,” Sensors, vol. 18,no. 8, pp. 1-19, 2018.

[31] Zhang v, Hu Z., Li Y., and Tang X., ”Grouping-based Clustering Routing Protocol in Wireless Sensor Networks,” IEEE, pp. 2452-2455, 2007.

[32] http://www.cs.miami.edu/ qcheng/papers/AWIC2006 _ci_v5.pdf .

[33] F. Dai and J. Wa, ” An extended localized algorithm for connected dominating set formation in Ad hoc wireless networks,” IEEE Trans Parallel and Distributed Systems, vol. 15, no. 10, pp. 1-13.

[34] Osamy W., Khedr A. M., Ahmed Aziza, and Ahmed El-Sawy, Cluster-Tree Routing Scheme for Data Gathering in Periodic Monitoring Applications, IEEE Access, Vol. 6, Page(s): 77372-77387.

[35] Osamy W., A. Salim, and Khedr A. M., An Information Entropy Based-Clustering Algorithm in Heterogeneous Wireless Sensor Networks, accepted in wireless networks, Springier, doi.org/10.1007/s11276-018-1877-y(0123456789.

[36] Hanif S., Khedr A. M., Z. Al Aghbari and Dharma P. Agrawal, Opportunistically Exploiting Internet of Things for Wireless Sensor Network Routing in Smart Cities, J. Sens. Actuator Netw. 2018, 7, 46; doi:10.3390/jsan7040046, 2018.

[37] Osamy W., Khedr A. M., An algorithm for enhancing coverage and network lifetime in cluster-based Wireless Sensor Networks, International Journal of Communication Networks and Information Security (IJCNIS) Vol. 10, No. 1, pp. 1- 9, April 2018

[38] Omar D. M., and Khedr A. M., Dharma P. Agrawal Optimized Clustering Protocol for Balancing Energy in Wireless Sensor Networks, International Journal of Communication Networks and Information Security (IJCNIS) Vol. 9, No. 3, pp. 367-375, December 2017.

[39] Khedr A. M., Effective Data Acquisition Protocol for Multi-hop Heterogeneous Wireless Sensor Networks Using Compressive Sensing, Algorithms, Vol. 8, No. 4, pp. 910-928; doi:10.3390/a8040910, 2105.

[40] Khedr A. M. and Omar D. M. , SEP-CS: Effective Routing Protocol for Heterogeneous Wire-less Sensor Networks, Ad Hoc & Sensor Wireless Networks, Vol. 26, pp. 211-232, 2015.

[41] Omar D., Khedr A. M. and Hamed Nassar, HCBHRP-CS: Effective Routing Protocol for Multi-level Heterogeneous Wireless Sensor Networks, Egyptian Computer Science Journal, Vol. 37, No. 4, May 2013.

[42] Aziz A., Karan Singh, W. Osamy, and A. M. Khedr, Effective Algorithm for Optimizing Compressive Sensing in IoT and Periodic Monitoring Applications, Journal of Network and Computer Applications, Volume 126, 15 January 2019, Pages 12-28.

[43] Omar D. and Khedr A. M., ERPLBC: Energy Efficient Routing Protocol for Load Balanced Clustering in Wireless Sensor Networks, Ad Hoc & Sensor Wireless Networks, Vol. 42, pp.145-169, 2018.

[44] Alsaafn A., Khedr A. M., Z. Al Aghbari, Distributed Trajectory Design for Data Gathering Using Mobile Sink in Wireless Sensor Networks, Int. J. Electron. Commun., AEU 96, pp. 1-12.