A comparative study of chain based routing algorithms in wireless sensor networks

Ahmed Salim[(1)], Asmaa Ahmed Badran[(2)]

[(1)]Department of Mathematics,
Faculty of Science, Zagazig University,
Zagazig, P. O. Box 44519, Egypt.
Department of Mathematics,
Faculty of Science and Arts, Al-mithnab,
Qassim University, P. O. Box 931, Buridah 51931,
Al-mithnab, Kingdom of Saudi Arabia.
asalim@zu.edu.eg
[(2)]Department of Mathematics,
Faculty of Science, Zagazig University,
Zagazig, P. O. Box 44519, Egypt.
asmaa.ahmedbadran@gmail.com

ABSTRACT

Many routing algorithms for Wireless Sensor Networks (WSNs) are designed and presented in the literature. The main target of these algorithms is to improve the performance of WSNs. In this paper, a comparative study of chain-based routing algorithms has been done. In this study, we compare the performances of PEGASIS [3], COSEN [6], IECBSN [8], CHAIN-BASED [15], CRA [12] and EAPHRN [9] algorithms when the mobile base station (BS) is used. We perform analytical simulations in terms of network lifetime and average energy consumption.

Indexing terms/Keywords

Wireless Sensor Network (WSN), Routing Protocol, Mobile Base Station.

Academic Discipline and Sub-Disciplines

Computer Science, Engineering, Information Technology.

SUBJECT CLASSIFICATION

Routing Protocol.

TYPE (METHOD/APPROACH)

Analysis and Modeling

1. INTRODUCTION

A WSN consists of a number of sensor nodes that are randomly deployed and transform physical data into a form that would make it easier for the user to understand [1]. The direct approach to collect data from sensor nodes is that each sensor node transmits the data directly to the BS. However, this approach consumes a lot of energy to transmit data from each sensor node to the BS, thus, nodes die very quickly and as a result reducing the network lifetime. Therefore, a few transmissions as possible is desirable for efficient energy utilization.

Many routing protocols have been proposed [3,4,6,7,8,9] in which consider reducing the amount of data transmissions in a WSN by fusing these sensing data and then transmit fused data to BS. A mobile BS can follow different types of mobility patterns in the sensor field, such as random mobility, or fixed path mobility, such as random mobility, or fixed path mobility, which has consequences with respect to energy efficiency and data collection strategies [13].

In this paper, a comparative study of chain based routing algorithms, PEGASIS[3], COSEN[6], IECBSN[12], CHAIN-BASED[15], CRA[12] and EAPHRN [9], is conducted by adding the concept of BS mobility in the algorithms and then compare the performance of these algorithms in terms of network lifetime and average energy consumption. The rest of the paper is organized as follows: Section 2 briefly reviews related work. In Section 3, we introduce our problem statement. The experimental simulation is proposed in Section 4. In Section 5, we conclude our work.

2. RELATED RESEARCH

Routing algorithms and data-gathering raises an important topic in WSNs due to the power limitation of sensor node [11]. There are two categories for the existing routing/data-gathering algorithms: hierarchy algorithms and non-hierarchy algorithms. In non-hierarchy algorithms, sensor nodes have the same role and collaborate to perform the sensing task and multi-hop communication. On the other hands, in the hierarchical algorithms, the network divided into several logical groups called clusters within a fixed area and nodes perform different tasks. The hierarchical algorithms include cluster based, tree-based and chain based routing protocols. In this paper, we focus on chain based routing protocols. The key in chain-based routing, however, is to form chains among the nodes so that each node will receive and transmit only to one pre-determined one-hop neighbor. Data is thereby aggregated through the chain until it reaches the chain leader, which transmits directly to the BS [14].

Many types of research in the last few years have explored chain-based routing in WSN from different perspectives. A variety of protocols has been proposed for prolonging the life of WSN and for routing data to the sink. PEGASIS (Power-Efficient gathering in Sensor Information Systems) [3] is the first and most popular energy-efficient chain based algorithm for WSNs that was proposed for reducing power consumption. PEGASIS introduces only a routing protocol that is near optimal for a data-gathering problem in WSNs. The main idea of the PEGASIS protocol is the formation of a chain among the sensor nodes so that each node will receive from and transmit to a close neighbor. Gathered data moves from node to node, are fused, and eventually, a designated node transmits it to the sink. In [4], the authors proposed an improved energy efficient PEGASIS based protocol (PEGASIS-E). PEGASIS-E uses average distance among the sensor nodes as the criteria for chaining, thereby providing better performance in terms of energy dissipation and amount of information sent to the sink. The simulation results obtained show that PEGASIS-E gives an increase in the network lifetime as compared to PEGASIS. Y.Song [5] proposed an Energy-Efficient Chain-Based routing protocol (EECB) that is an improvement over PEGASIS. EECB uses distances between nodes and the base station and remaining energy levels of nodes to decide which node will be the leader that takes charge of transmitting data to the base station. In [6], the authors proposed a Chain Oriented Sensor Network (COSEN) protocol, which is a two-layer protocol where a number of chains are formed in order to cover the whole region. COSEN reduce the latency associated with the original PEGASIS protocol by forming multiple smaller chains instead of a single longer chain. At first several small, fixed-length chains constructed using the same distance-based greedy heuristic of the original PEGASIS protocol and a chain leader is selected in each chain based on the highest remaining energy. Leader nodes are selected for a certain number of rounds. These chain leaders again create a higher-level chain and among those leaders, one is chosen depending on the distance to the sink and remaining energy level; to accumulate all data from the network and send that data to the sink at each round whereas other nodes only communicate with its neighbor in the chain .

Energy Efficient Chain Based Sensor Network (ECBSN) [7] overcomes several problems of PEGASIS. ECBSN overcomes the problem of excessive delay; instead of one long chain in the network, numbers of short chains are formed. In ECBSN, every first node in a chain becomes a leader node. Thus, it ignores the suitable proportion of nodes energy and distance between node and BS, which optimize the leader selection according to the various application environments. ECBSN protocol has certain deficiencies like the non-optimal selection of leader nodes in rounds, aggregation, and transmission of data by head nodes that leads to unbalanced energy consumption [8]. An improved ECBSN protocol called IECBSN is proposed in [8]. IECBSN adopts a new method of selection of leader nodes based on selection value (SV) parameter, which outperforms ECBSN. EAPHRN (Energy Aware PEGASIS Based Hierarchical Routing) [9] is a chain based routing protocol in which node does not connect to the next closest node but connects to a random node that is not far than the Distance Threshold (DT). EAPHRN is divided into two phases, Chain Setup phase, and Leader election phase. A Chain-Based Routing Protocol to Maximize the Lifetime of Wireless Sensor Networks (CHAIN-BASED) proposed in [15]. CHAIN-BASED is based on constructing multiple chains in the direction of the BS. The first node of each chain sends data to the closest node in the same chain. This latter collects aggregates and transmits data to the next closest node. This process repeats until reaching the last node, which aggregates and transmits data directly to the BS. The work in [10] is similar to our work, the authors compare five hierarchal cluster-based routing protocols and introduce the mobility of BS in the five protocols and compare their performance. The main difference between our work and [10] is that our work provides analytical simulations in terms of network lifetime and average energy consumption for different chain based routing protocols.

3. PROBLEM STATEMENT

Our objective is to analyze the performance of the chain routing algorithms when using a mobile BS. We compare chain based routing algorithms such as CRA, PEGASIS, CHAIN-BASED, COSEN, IECBSN, and EAPHRN, by implementing the concept of BS mobility in them. Their performances are observed and compared. The position of BS is varied at different locations within the network area according to different scenarios.

In the proposed scenarios, we consider data collected by a single mobile BS traveling through proposed mobility scenario in the monitored region. Initially, BS starts motion from the initial position of the bounded services area. BS changes its relative position according to the different mobility scenarios (random, and predetermined (Fixed path)).

3.1Random mobility scenario

In random mobility scenario, the BS initially is placed randomly on the edge of the area. Then a destination is randomly chosen and the BS moves towards this destination. Upon arrival, the BS pauses for a time and again chooses a new destination for the next movement. As a result, the BS is staying in a location for a certain period of time (pause time). While the BS is staying in a location for a certain period, it broadcasts a start message to the network nodes. After receiving the start message each head node sends the data packets to the BS until receives the stop message. Before the BS changes its position, it broadcasts another message to reset the nodes and stop the transmission, to reduce the packet drop. After that, BS changes to a new position and follow the same steps every time [16, 17]. We use pause time because BS needs to collect the data packets before change its position and we have taken long pause time equals to round's time.

3.2Predetermined scenarios

We consider three different predetermined scenarios, rectangle [18], circle [19] and middle path [17].

- Rectangle mobility scenario: in rectangle mobility scenario, the BS moves along rectangle trajectory along the boundary of the network and pauses to collect data during round period then moves to next point.

- Middle path mobility scenario: in this scenario, the BS moves back and forth along the path at the middle of the network and pause for a period to collect data.

- Circle mobility scenario: in circle mobility scenario, the BS circles along the boundary of the network and pauses to collect data during round period then moves to next point in the next round.

4. EXPERIMENTAL SIMULATION

We modified the WSN simulator developed by David J. Stein [20]. The simulation consists of two stages: deploying the network and running simulations. The simulator is written in C# using Microsoft Visual Studio.NET.

In our simulation, 100 sensor nodes are randomly deployed in a region of size 200m x 200m on a two-dimensional plane and are uniformly distributed with BS (static and mobile).

4.1 Energy Model

In order to measure the energy consumption of sensor nodes, we use the same energy parameters and radio model as discussed in [2], wherein energy consumption is mainly divided into two parts: receiving and transmitting messages. The transmission energy consumption needs additional energy to amplify the signal depending on the distance to the destination. Thus, to transmit a k-bits message a distance d, the radio power consumption will be,

$$E_{Tx}(k,d) = \begin{cases} kE_{Tx} + k\epsilon_{fs}d^2 & d < d_0 \\ kE_{Tx} + k\epsilon_{mp}d^4 & d \geq d_0 \end{cases} \qquad (1)$$

and to receive this message, the radio expend will be

$$E_{Rx}(k) = k * E_{elec.} \quad (2)$$

where d is the distance between sender and receiver, $E_{Tx}(k,d)$ is the cost of transmitting an k-bit message for a distance d, $E_{Rx}(k)$ is the cost of receiving and l-bit message for a distance d, E_{elec} is the electronics energy that depends on the circuit itself, ϵ_{mp} is the energy consumed by the transmitter amplifier for longer distance, ϵ_{fs} the energy consumed by the transmitter for shorter distance, the threshold distance $d_0 = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}}$ and E_{DA} is the energy for data aggregation.

The simulated model parameters are given in Table 1.

Table1 Parameters used in the simulation

Parameter	Value
Network size	200 x 200
BS location	Fixed at (100,100), (100, 200) , or (100,300) Mobile (random, rectangle, circle or middle path)
Number of nodes	100
Initial energy	2 unit
E_{elec}	50 nJ/bit
ϵ_{fs}	10 $pJ/bit/m^2$
ϵ_{mp}	0.00013 $pJ/bit/m^4$
d_0	87m
E_{DA}	5 $nJ/bit/signal$
Data packet size	2000bits

4.2 Performance Metrics

In two different scenarios, Static BS and Mobile BS (random, rectangle, circle, and middle path) we use the following performance metrics to indicate the performance of algorithms (COSEN, EAPHRN, IECBSN, PEGASIS, CHAIN-BASED, and CRA):

- **Average Energy Consumption:** It is the average energy consumed by all the nodes in sending, receiving and forwarding operations.

    The average energy consumption per round until the first node die can be estimated as:

$$E_{Average} = \frac{\sum_{i=1}^{N} E_i}{r}$$

Where *N* is the number of sensor nodes, and r is the number of rounds.

- **Network Lifetime:** It is the time interval from the start of operation (of the sensor network) until the death of the first alive node.

4.3 Results and Discussion

Table 2 and Table 3 show the simulation results for static BS at different locations (100,100), (100,200), and (100,300).

Table 2: Network lifetime in each algorithm for static BS scenario

	100x100	100x200	100x300
COSEN	573.07	562.5347	560.72
EAPHRN	522.35	479.19	509.32
IECBSN	519.12	507.37	528.24
PEGASIS	525.24	510.98	496.14
CHAIN-BASED	574.06	481.44	187.06
CRA	726.09	676.91	522.32

Figure 1 shows the network lifetime for COSEN, EAPHRN, IECBSN, PEGASIS, CHAIN-BASED and CRA. We can notice that the network lifetime of CRA exceeds the network lifetime of EAPHRN, PEGASIS, CHAIN-BASED, COSEN and IECBSN if the locations of BS varies between (100, 100) and (100, 200). IECBSN and COSEN perform significantly better than the proposed CRA if the BS is located far away from the network. This is because in CRA there is long distance between the BS and the leader nodes that want to send data, however IECBSN and COSEN have two levels of leaders (lower level with many leaders send their data to higher level leader node), which save the energy comparing with the CRA, PEGASIS, CHAIN-BASED, or EAPHRN. Figure 2 presents the average energy consumption in COSEN, EAPHRN, IECBSN, PEGASIS, CHAIN-BASED and CRA algorithms.

Table3: Average energy consumption in each algorithm for static BS scenario

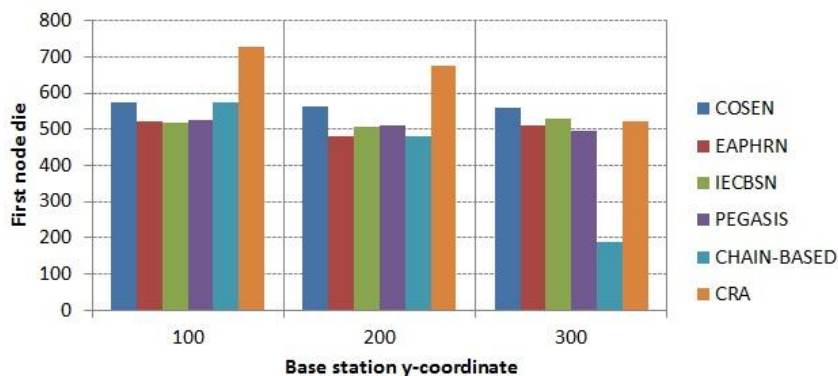|	100x100	100x200	100x300
COSEN	0.255647643	0.255901971	0.258197348
EAPHRN	0.304535876	0.307640938	0.306699823
IECBSN	0.282961763	0.283704029	0.28348932
PEGASIS	0.292796647	0.294769337	0.301976181
CHAIN-BASED	0.259276007	0.260505494	0.273924397
CRA	0.257980433	0.262804498	0.293179003

Figure1: Network lifetime for a 200x200 network as the BS locations varies between (100, 100) and (100, 300) in COSEN, EAPHRN, IECBSN, PEGASIS, CHAIN-BASED and CRA algorithms.
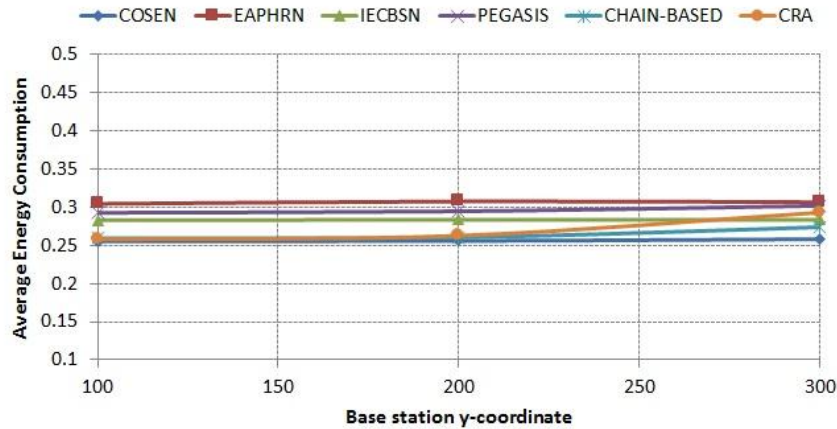
Figure2:Average Energy Consumption in COSEN, EAPHRN, IECBSN,PEGASIS,CHAIN-BASED and CRA algorithms for different BS locations (between (100, 100) and (100, 300))

Table 4: Average energy consumption cost in each algorithm for different mobility scenarios

	Circle	Middle path	Random	Rectangle
COSEN	0.255727026	0.256042456	0.255521409	0.255921134
EAPHRN	0.308412594	0.309073354	0.308112939	0.308070225
IECBSN	0.284099221	0.285002075	0.285450195	0.284607583
PEGASIS	0.296928267	0.295731794	0.29677469	0.296735927
CHAIN-BASED	0.266013152	0.261068514	0.263409185	0.269088393
CRA	0.262815304	0.259471794	0.261125908	0.265068197

Table5 : Network lifetime in each algorithm for different mobility scenarios

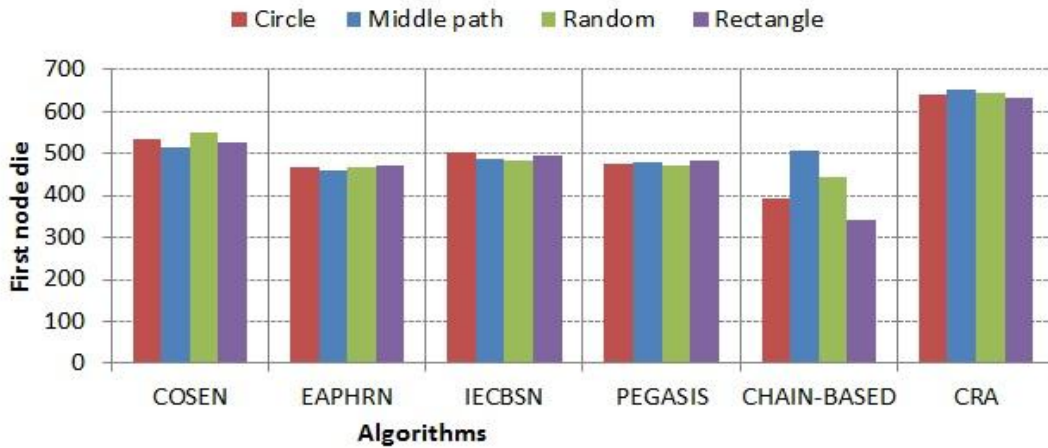|	Circle	Middle path	Random	Rectangle
COSEN	533.6	516.05	549.45	524.94
EAPHRN	466.47	459.18	467.76	471.85
IECBSN	500.67	487.96	483.44	493.78
PEGASIS	475.47	480.76	471.48	482.49
CHAIN-BASED	394.39	504.9	444.71	339.89
CRA	638.21	652.57	643.34	630.47

Figure 3: Network lifetime for a 200x200 network with different mobility scenarios (random and predetermined
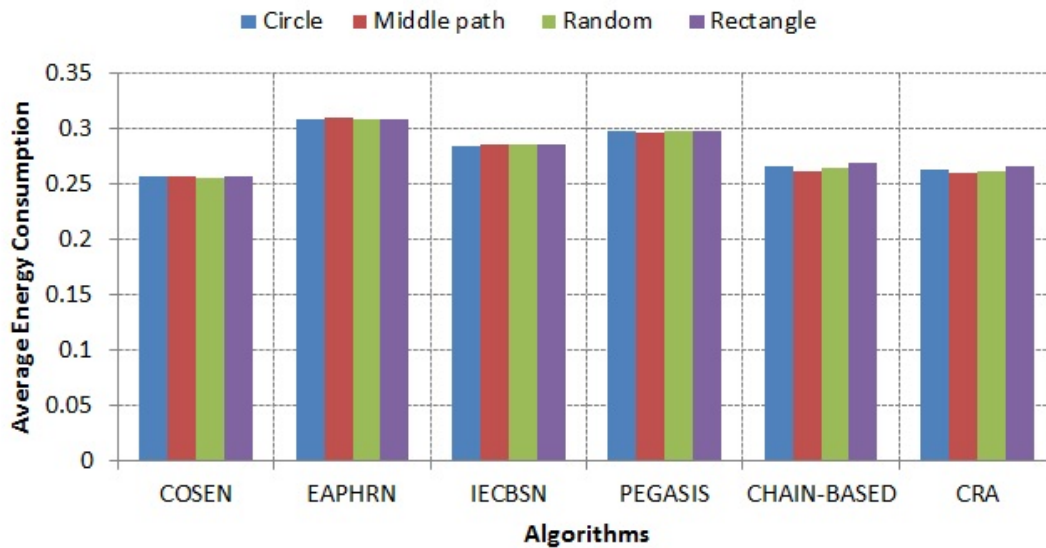

Figure 4: Average Energy Consumption for a 200x200 network with according to different mobility scenarios (random and predetermined).

Table 4 and Table 5 show the simulation results for mobile. Figure 3 and Figure 4 show the lifetime and average energy consumption for PEGASIS, CHAIN-BASED, COSEN, IECBSN, CRA and EAPHRN in the case of mobile BS.

As shown in Table 4 and Figure 3, COSEN gives better network lifetime in case of random mobility scenario and IECBSN gives better network lifetime in case of circle mobility scenario, moreover, PEGASIS and EAPHRN gives better network lifetime in case of rectangle mobility scenario. While   CRA and CHAIN-BASED give better network lifetime in the case of middle path scenario.

As shown in Table 5 and Figure 4, COSEN gives minimum average energy consumption in case of random mobility scenario, IECBSN gives minimum average energy consumption in the case of circle mobility scenario, and EAPHRN gives minimum average energy consumption in case of rectangle mobility scenario, while   PEGASIS, CRA, and CHAIN-BASED give minimum average energy consumption in case of middle path scenario.

From Figure 1 and Figure 3, we can observe that the network lifetime in COSEN, EAPHRN, PEGASIS is decreased in all mobility scenario compared to the static BS. However, the network lifetime in CHAIN-BASED and CRA is increased in all   mobility scenario compared to the static BS at (100,300), and for CHAIN-BASED the network lifetime increased only in case of middle path mobility scenario compared to the static BS at (100, 200). While decreased in all mobility scenario compared to the static BS at (100,100) for CHAIN-BASED and CRA.

From Figure 2 and Figure 4, we can notice that the average energy consumption for COSEN decreased in case of random mobility scenario compared to the BS at (100,100) and decreased in case of all mobility scenarios compared to the BS at (100,300), while the average energy consumption for COSEN increased only in case of rectangle mobility scenario compared to the BS at (100, 200). The average energy consumption for EAPHRN and IECBSN is increased in all mobility scenarios compared to the BS at (100,100), (100,200), (100,300). In addition to that the average energy consumption for PEGASIS and CHAIN-BASED increased in all mobility scenarios compared to the BS at (100,100), (100,200), while decreased in all mobility scenarios compared to the BS at (100, 300).

Moreover, the average energy consumption for CRA increased in all mobility scenarios compared to the BS at (100, 100) and decreased compared to the BS at (100,300). However, the average energy consumption for CRA increased in the case of circle and rectangle mobility scenarios and decreased in case of random and middle path mobility scenarios decreased compared to the BS at (100,200).

In summary, by comparing the network lifetime and average energy consumption of all algorithms in both cases, mobile and static BS (by considering the average values of different BS locations) scenarios; it is concluded that the network lifetime of CRA, CHAIN-BASED is increased in the case of middle path and random, while decreased for PEGASIS, COSEN, IECBSN and EAPHRN in the case of all mobility scenarios of the BS. In addition to that the average energy consumption is increased in all mobility scenarios for PEGASIS and IECBSN, while decreased for COSEN in the case of random mobility, for PEGASIS decreased slightly in the case of middle path, for CHAIN-BASED decreased in case of middle path and random mobility, and for CRA decreased in all cases of mobility scenarios.

5. CONCLUSION

In this paper, we have introduced the mobility of sink in all proposed protocols, COSEN, EAPHRN, IECBSN, PEGASIS, CHAIN-BASED and CRA to compare their performances. We have introduced two scenarios are discussed to compare the performances of chain based algorithms; in the first scenario, static BS is used and in the later one mobile BS is used. We have proposed different mobility scenarios, random, circle, middle path and rectangle mobility. In our future work, we aim to find the optimal path for BS movement and incorporate multiple BSs in the network.

REFERENCES

[1] D. Estrin, R. Govindan, J. Heidemann, S. Kumar, Next century challenges: scalable coordination in sensor networks," in Proceedings of the 5th Annual ACM/IEEE International Conference on Mobile Computing and Networking, Seattle, Washington, USA, pp. 263-270, 1999.

[2] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, Energy-efficient communication protocol for wireless microsensor networks, Proceedings of the 33rd Hawaii International Conference on System Sciences, pp. 1-10, 2000.

[3] S. Lindsey and C. Raghavendra, PEGASIS: Power-Efficient gathering in sensor information systems, in Aerospace Conference Proceedings, 2002, Vol. 3, pp.1125 - 1130.

[4] Vibha Nehra, Ajay K. Sharma, PEGASIS-E: Power-Efficient Gathering in Sensor Information System Extended, Global Journal of Computer Science and Technology Network, Web and Security, Vol. 13, no. 15, 2013.

[5] Yu, Yongchang, and Yichang Song., An energy-efficient chain-based routing protocol in wireless sensor network. Computer Application and System Modeling (ICCASM), 2010 International Conference on. Vol. 11. IEEE, 2010, pp. 486-489.

[6] Nahdia Abassum, Quazi Ehsanul Kabir Haque Mamun, AKM Ahsanul and Yoshiyori Urano , A Chain Oriented Data Collection Protocol for Energy-Aware and Delay-Constrained WSN, African Journal of Information and Communication Technology, Vol.2, no.3,pp.11,2006.

[7] Shilpa Mahajan and Jyoteesh Malhotra, Enhanced Chain Technique Based Data Collection Sensor Network, International Journal of Computer Science, Vol. 8, No. 3, 2011, pp. 83- 87.

[8] Shilpa Mahajan, Jyoteesh Malhotra, and Sandeep Sharma. Improved Enhanced Chain Based Energy Efficient Wireless Sensor Network. Wireless Sensor Network 5 (2013): 84-89.

[9] H Alhasan, M Qatawneh, A Sleit, W Almobaideen, EAPHRN: energy-aware PEGASIS-based hierarchal routing protocol for wireless sensor networks, Journal of American Science, 2011.

[10] Javaid, Nadeem, Ain, Q., Khan, M. A., Javaid, Akmal, Khan, Z. A. and Qasim, U., On Sink Mobility Trajectory in Clustering Routing Protocols in WSNs. CoRRabs 1304.0984 (2013).

[11] Z. Manap, B. M. Ali, C. K. Ng, N. K. Noordin, and A. Sali, A review on hierarchical routing protocols for wireless sensor networks," Wireless Personal Communications, vol. 72, no. 2, pp. 1077–1104, 2013.

[12] A. Salim, A.Badran., Effective Chain-based Routing Algorithm for Wireless Sensor Networks, Journal of Coputational and Theoretical Nanoscience, 2016.

[13] M. I. Khan, W. N. Gansterer, and G. Haring, Static vs. mobile sink: The Influence of basic parameters on energy efficiency in wireless sensor networks, Comput. Commun., vol. 36, pp. 965-978, May 2013.

[14] Kim Öberg, System design choices in smart autonomous networked irrigation systems, Master of Science Thesis Stockholm, Sweden 2014.

[15] H. Guyennet, M. Hadjila, and M. Feham, A chain-based routing protocol to maximize the lifetime of wireless sensor networks," vol. 05, pp. 116(120), 2013.

[16] D. Puthal, B. Sahoo, and S. Sharma, Dynamic model for efficient data collection in wireless sensor networks with mobile sink, IJCST, vol. 3, Mar. 2012.

[17] J. Wang, X. Yang, B. Li, and S. Lee, A mobile sink based uneven clustering algorithm for wireless sensor networks, Journal of Internet Technology, vol. 14, pp. 895-902, Nov. 2013.

[18] J. Wang, B. Li, F. Xia, C.-S. Kim, and J.-U. Kim, An energy efficient distance-aware routing algorithm with multiple mobile sinks for wireless sensor networks, Sensors, vol. 14, no. 8, p. 15163, 2014.

[19] L. Li, T. Ma, S. Ji, and J. Wang, Jeong-Uk Kim A circle-based data dissemination algorithm for wireless sensor networks with mobile sink," International Journal of Smart Home, vol. 7, pp. 35-46, Jan. 2013.

[20] D. J. Stein, Wireless sensor network simulator ver1.1, 2005. http://ekendraonline.com/sensor-networks/wireless-sensor-network-simulator/.