An Energy Efficient Chain-based Routing Protocol for Wireless Sensor Networks

Razieh Sheikhpour[1], Sam Jabbehdari[2]
[1] Young Researchers and Elites Club, North Tehran Branch, Islamic Azad University, Tehran, Iran
[e-mail: r_sheikhpour@yahoo.com]
[2] Department of Computer Engineering, North Tehran Branch, Islamic Azad University, Tehran, Iran
[e-mail: s_jabehdari@ iau-tnb.ac.ir]
*Corresponding author: Razieh Sheikhpour

Received December 4, 2012; revised February 23, 2013; revised April 18, 2013; accepted May 18, 2013; published June 26, 2013

Abstract

Energy constraint of wireless sensor networks makes energy saving and prolonging the network lifetime become the most important goals of routing protocols. In this paper, we propose an Energy Efficient Chain-based Routing Protocol (EECRP) for wireless sensor networks to minimize energy consumption and transmission delay. EECRP organizes sensor nodes into a set of horizontal chains and a vertical chain. Chain heads are elected based on the residual energy of nodes and distance from the header of upper level. In each horizontal chain, sensor nodes transmit their data to their own chain head based on chain routing mechanism. EECRP also adopts a chain-based data transmission mechanism for sending data packets from the chain heads to the base station. The simulation results show that EECRP outperforms LEACH, PEGASIS and ECCP in terms of network lifetime, energy consumption, number of data messages received at the base station, transmission delay and especially energy× delay metric.

Keywords: Wireless sensor network, Hierarchical routing protocol, Energy efficient, Chain-based routing

http://dx.doi.org/10.3837/tiis.2013.06.001

1. Introduction

Wireless sensor networks have emerged as state of the art technology in gathering data from remote locations by interacting with physical phenomena [1][2]. A wireless sensor network is composed of hundreds or thousands of sensor nodes which are usually battery-powered and deployed in an unprotected environment to collect the surrounding information and then transmit report messages to a remote base station [2][3][4][5][6]. The base station aggregates and analyzes the report messages received and decides whether there is an unusual or exceptional event occurrence in the deployed region [4].

Energy efficiency has been known as the most important issue in the research of wireless sensor networks. Hierarchical techniques have emerged as a popular choice for achieving energy efficiency in wireless sensor networks [2][4][7][8][9][10].

Most of the hierarchical routing protocols proposed by researchers have used clustering approach for routing in wireless sensor network and a few hierarchical routing protocols use chain based data transmission mechanism in wireless sensor network. In this paper, an Energy Efficient Chain based Routing Protocol (EECRP) for wireless sensor networks are proposed to minimize energy consumption and transmission delay and especially energy × delay metric.

EECRP organizes sensor nodes into a set of horizontal chains and a vertical chain. Chain heads are elected based on residual energy of nodes and distance from the header of upper level. In each horizontal chain, sensor nodes transmit their data to their own chain head based on chain routing mechanism. EECRP also improves the data transmission mechanism from the chain heads to the base station via constructing a chain among the chain heads.

Performance of the proposed protocol was evaluated via simulations and it was compared with performance of LEACH, PEGASIS and ECCP. The simulation results show that the proposed protocol can outperform in terms of network lifetime, energy consumption, number of data messages received in the base station, transmission delay and especially energy × delay metric.

The rest of this paper is organized as follows: Section 2 presents an overview of related work. Section 3 describes the assumptions and radio energy dissipation model. The proposed scheme (EECRP) is presented in Section 4. The simulation results are presented in Section 5. Finally, the main conclusions are presented in Section 6.

2. Related Work

Recently, a lot of hierarchical routing protocols for reducing energy consumption of wireless sensor nodes have been proposed. In this section, some of the hierarchical routing protocols in wireless sensor networks are reviewed.

One of the most popular cluster-based routing protocols in wireless sensor networks is LEACH. The operation of LEACH is divided to rounds. Each round begins with a setup phase when the clusters are organized, followed by a steady state phase when data are transmitted from the nodes to the cluster head and on to the base station. LEACH randomly selects a few nodes as cluster heads and rotates this role to balance energy dissipation of the sensor nodes in the network [11][12].

LEACH-Centralized [12] uses a centralized clustering algorithm. In the setup phase, the base station receives all the information about each node regarding its location and energy status. The base station runs local algorithm for the formation of cluster heads and clusters and broadcasts a message that contains the cluster head ID for each node. The steady state phase of LEACH-C is identical to that of the LEACH protocol.

In [12], LEACH with fixed clusters (LEACH-F) was proposed. LEACH-F is based on clusters that are formed once in the first setup phase by the base station and then fixed. The cluster head position rotates among the sensor nodes within the cluster. LEACH-F uses the same centralized cluster formation algorithm as LEACH-C. The fixed clusters in LEACH-F do not allow new nodes to be added to the system and do not adjust their behavior based on nodes' death.

PEGASIS [13] is an improvement of the LEACH protocol. The main idea in PEGASIS is to form a chain among sensor nodes so that each node receives from and transmits to a close neighbor. The gathered data move from node to node, get fused and eventually a designated node transmits them to the base station. In PEGASIS, the chain construction is done in a greedy fashion with the assumption that all the nodes have global knowledge of the network. PEGASIS outperforms LEACH by eliminating the overhead of dynamic cluster formation, minimizing the distance non-leader nodes must transmit, limiting the number of transmissions and receiving among all nodes and using only one transmission to the base station per round.

TEEN [14] is a routing protocol for time critical applications to respond to changes in the sensed attributes such as temperature. After the clusters are formed, the cluster head broadcasts two thresholds to the nodes. These are hard and soft thresholds for the sensed attributes. The hard threshold aims at reducing the number of transmissions by allowing the nodes to transmit only when the sensed attribute is in the range of interest. The soft threshold will further reduce the number of transmissions if there is little or no change in the value of sensed attribute. One can adjusts both hard and soft threshold values in order to control the number of packet transmissions. The advantage of this scheme is its suitability for time critical applications and also the fact that it significantly reduces the number of transmission.

APTEEN [15] is an extension of TEEN and aims at capturing periodic data collections and reacting to time critical events. APTEEN allows the sensor node to send its sensed data periodically and react to any sudden change in the value of the sensed attribute by reporting the corresponding values to their cluster heads. The main drawbacks of TEEN and APTEEN are the overhead and complexity associated with forming clusters at multiple levels.

An Energy Efficient Clustering Protocol (EECPL) [16] has been proposed to enhance lifetime of wireless sensor networks. EECPL considers a cluster head and a cluster sender for each cluster. The cluster head creates and distributes the TDMA schedule, which specifies the time slots allocated for each member of the cluster. The cluster sender is responsible for sending the aggregated data to the base station. The idea in EECPL is to form a ring among the sensor nodes within cluster so that each sensor node receives from a previous neighbor and transmits to the next neighbor. Upon receiving the aggregated data from previous neighbors, cluster senders transmit the aggregated data to the base station directly.

HEED [17] periodically selects cluster heads according to a hybrid of their residual energy and a secondary parameter such as node proximity to its neighbors or node degree. HEED does not make any assumptions about the distribution or density of nodes or about node capabilities. The clustering process terminates in O(1) iterations and does not depend on the network topology or size. The protocol incurs low overhead in terms of processing cycles and exchanged messages. It also achieves fairly uniform cluster head distribution across the network. A careful selection of the secondary clustering parameter can balance load among cluster heads.

Lee et al. proposed a Cluster Based Energy Efficient Routing Protocol (CBERP) for wireless sensor networks [18]. CBERP divides sensor nodes to clusters and selects the cluster heads as LEACH-C. However, CBERP advances the cluster head selection mechanism by utilizing a number of candidate nodes to reduce the overhead. After selecting the cluster heads, it forms a chain of the cluster heads and transmits data to the base station through the chain.

Tang et al. proposed a Chain-Cluster based Mixed routing (CCM) algorithm for wireless sensor networks [19], which divides a wireless sensor network to a few chains and a cluster. CCM algorithm is run in two stages. In the first stage, sensor nodes in each chain transmit data to their own chain head using the chain based routing. In the second phase, all the chain heads form a cluster and send the data, which are fused from their own chains, to a voted cluster head. Finally, the cluster head further fuses data and transmits them to the remote base station.

Zarei et al. proposed a Cluster Based Routing Protocol (CBRP) for prolonging the lifetime of wireless sensor networks [2]. The operation of CBRP is divided to rounds and each round of this protocol consists of two phases of setup phase and steady state phase. In the setup phase, clusters are generated and then, in the steady state phase, a spanning tree is constructed for sending aggregated data to the base station. Only the root node of this tree can directly communicate with the base station.

In [21], an Energy Efficient Cluster-Chain based Protocol (ECCP) was proposed for wireless sensor networks. The main goal of ECCP is to distribute energy load among all sensor nodes in order to minimize energy consumption in wireless sensor networks. ECCP organizes sensor nodes into clusters and constructs a chain among the sensor nodes within each cluster. Furthermore, ECCP forms a chain among the cluster heads. In ECCP, cluster heads are elected in a distributed way based on residual energy of nodes, distance from neighbor nodes and number of the neighboring nodes. In ECCP, each node maintains a neighborhood table to store the information about its neighbors. Each round of this protocol consists of clustering phase, chain formation phase and data transmission phase. In ECCP, clustering phase is not performed in each round and sensor nodes use residual energy levels to select new cluster heads for the next round. If any sensor node dies in the cluster, the cluster head sends a message to the base station and informs it that the sensors should hold the clustering phase at the beginning of the upcoming round. ECCP uses a hybrid clustering approach for minimizing energy consumption.

ECCP was extended for time critical applications (ECCPTC) to reduce transmission delay of time critical data [22]. In ECCPTC, the nodes react immediately to sudden changes in the value of a sensed attribute. ECCPTC considers higher priority for time critical data compared with non-time critical data so that time critical data are immediately transmitted to the base station. ECCPTC uses a threshold value for reducing transmission delay of time critical data. If the sensed data value by a sensor node is equal to or greater than threshold value, the sensed data are considered as time critical data and should be immediately transmitted to the base station.

3. Assumptions and Radio Energy Model

A sensor network consisting of *N* sensor nodes uniformly deployed over a vast field are considered for continuously monitoring the environment. In this paper, the following assumptions are assumed for the sensor network.

- Nodes are dispersed randomly following a uniform distribution in a 2-dimensional space.
- Sensor nodes and the base station are all stationary after deployment.
- The base station is considered a powerful node with enhanced communication and computation capabilities with no energy constraints.
- All sensor nodes in the network are homogenous and energy-constrained.
- All sensor nodes are location aware, i.e. equipped with GPS-capable antennae.
- Sensor nodes have CDMA functionalities.
- Links are symmetric. A node can compute the approximate distance to another node based on the received signal strength if the transmitting power is known.

3.1 Radio Energy Dissipation Model

The energy model presented in [11][12] is adopted for the communication energy dissipation. The energy expended to send a *k*-bit message over a distance *d* for each sensor node is as in Eq. (1).

$$E_{Tx}(k,d) = \begin{cases} kE_{elec} + k\varepsilon_{fs}d^2 & ,d < d_0 \\ kE_{elec} + k\varepsilon_{amp}d^4 & ,d \geq d_0 \end{cases} \quad (1)$$

where E_{elec} is the amount of energy consumed in electronics and ε_{amp} and ε_{fs} are the energy consumed in amplifiers.

The energy expended in receiving a *k*-bit message is as shown Eq. (2).

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

The energy expended for aggregating *m* data packets to a single packet is as follows (in Eq. (3)).

$$E_{fuse}(m,k) = m * k * E_{DA} \quad (3)$$

4. EECRP- the Proposed Protocol

In PEGASIS [13] that is a chain based routing protocol for wireless sensor networks, a chain is formed among the sensor nodes so that each node receives from a previous neighbor and transmits to a next neighbor. PEGASIS significantly induces a much longer data transmission delay because of the large number of hops in a long chain. In ECCP [21] that is a cluster-chain based routing protocol for wireless sensor networks, sensor nodes are organized into clusters. When a sensor node dies in the cluster, ECCP suffers from cluster formation overhead. ECCP increases transmission delay compared with LEACH. In ECCP, each node maintains a neighborhood table to store information of its neighbors that causes waste of memory space of sensor nodes. For selecting the leader of the cluster heads, the cluster heads send their location information to the base station. Based on the received information, the base station creates a chain of cluster heads and sends it to the cluster heads. This causes waste of time and energy. In ECCPTC [22] that is a cluster-chain based routing protocol for wireless sensor networks, sensor nodes react immediately to sudden changes in the value of a sensed attribute. ECCPTC considers higher priority for time critical data compared with non-time critical data so that time critical data are immediately transmitted to the base station. In ECCPTC, transmission delay of non-time critical data is increased. The main drawbacks of ECCP and ECCPTC are the higher overhead associated with forming clusters when a sensor node dies in the cluster. Also, ECCP and ECCPTC use a complex hybrid clustering approach for reducing energy consumption.

In order to avoid these situations, we propose an Energy Efficient Chain-based Routing Protocol (EECRP) for wireless sensor networks to minimize energy consumption and transmission delay. The proposed protocol organizes sensor nodes as a set of horizontal chains and a vertical chain. In each chain, a node is selected as chain head. For selecting the chain heads in horizontal chains, EECRP considers residual energy of nodes and distance of nodes from the header of upper level that does not need to reselect leader of the vertical chain. This causes time and energy saving. In each horizontal chain, sensor nodes transmit their data to their own chain head based on chain routing mechanism. EECRP also adopts a chain based data transmission mechanism for sending data packets from the chain heads to the base station. EECRP does not use a complex hybrid approach for reducing energy consumption as ECCP.

In the proposed protocol, the network is divided to a set of strips as shown in **Fig.1.** It is assumed that “h” is height of each strip and there are “k” strips in the sensor network, computed by “k=L/h”, where “L” is length of wireless sensor network.

In each strip, a chain is formed among the sensor nodes and a chain head is selected. In order to balance energy consumption among all sensor nodes in the network, the chain head’s role should be rotated among the sensor nodes to prevent their exhaustion.

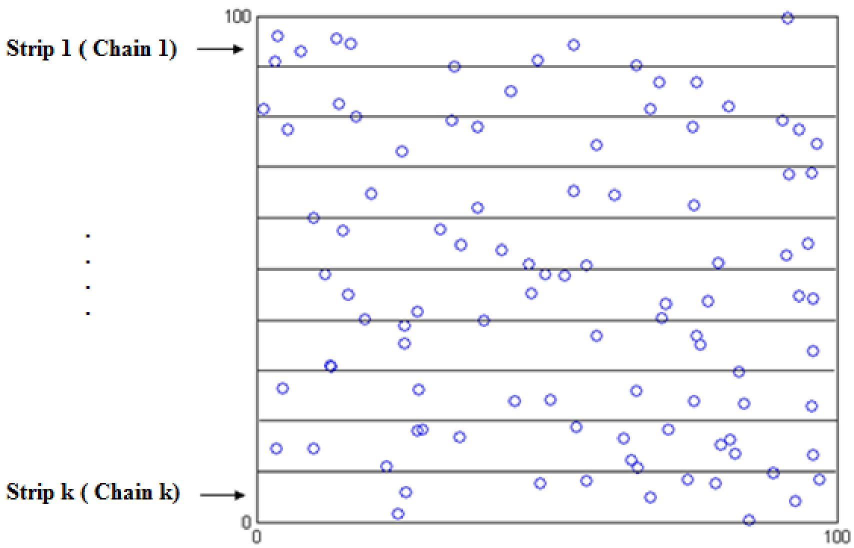

Fig. 1. A sensor network with k strips (chains)

The operation of the EECRP protocol is organized as rounds. Each round of this protocol consists of the following phases.

- Setup phase
- Data transmission phase

4.1 Setup Phase

Setup phase consists of three stages:

4.1.1 Selection of Chain Heads

In this stage, each node directly sends a control packet with information about its current location and energy level to the base station. Since control packet size is small, each node directly sends it to the base station. Base station uses this information to select the chain heads. Base station selects the header of each strip based on the residual energy of nodes and the distance of nodes from the header of upper level. Base station is located at the highest levels and calculates the "CHSV" of each node (Chain Head Selection Value) using Eq. (4); then, it selects the node with the highest CHSV in each strip as the chain head.

$$\mathrm{CHSV_i} = \frac{\mathrm{RE_i}}{\mathrm{dist^2_{to\ upper\ CH}}} \tag{4}$$

where "$\mathrm{RE_i}$" denotes residual energy of node "i" and $\mathrm{dist}^2_{\text{to upperr CH}}$ is the distance of node "i" from header of the upper level.

4.1.2 Creation of Horizontal Chains

After the selection of chain heads, the base station applies the greedy algorithm used in PEGASIS to make a chain among the sensor nodes in each strip (horizontal chain) so that each sensor node receives data from a previous neighbor, aggregates its data with the one received from its previous neighbor and transmits the aggregated data to the next neighbor.The chain is formed from the furthest to the nearest node from the chain head.

4.1.3 Creation of a Vertical Chain

EECRP also creates a chain among the chain heads (vertical chain). The selection of chain heads in horizontal chains is done in such a way that does not need to reselect the leader of the vertical chain and chain head of strip 1 (level 1) acts as the leader of chain heads so that all the chain heads send data to the leader node through the chain; finally, the leader node aggregates data and transmits them to the base station. This saves most of the chain heads from the high power transmissions to the distant base station and protects them from early exhaustion.

Once the chains are formed, the base station broadcasts a message that contains the chain and chain head ID for each node. If a node's chain head ID matches its own ID, the node is a chain head.

4.2 Data Transmission Phase

The data transmission phase is divided to several frames and sensor nodes transmit and receive data at each frame. Data transmission phase consists of two stages:

4.2.1 Data Transmission among Sensor Nodes in Horizontal Chains

For gathering data in each frame, sensor nodes in each chain transmit their data to their own chain head using the chain based routing. EECRP uses a simple control token passing approach initiated by the chain head to start data transmission from the ends of the chain. The cost is very small since the token size is very small. The two end nodes in a chain transmit data and tokens to their individual neighboring nodes in parallel. Each sensor node receives data and token from previous neighbor, aggregates the data with its own data and transmits aggregated data and token to the next neighbor in the chain. The data are transmitted in an alternative way until all the data are transmitted to the chain head node.

4.2.2 Data Transmission among Chain Heads in the Vertical Chain

In this stage, base station generates a token and transmits it to the end chain head node in the vertical chain. Each chain head aggregates its neighbor's data with its own data and transmits aggregated data to the next neighbor in the vertical chain. Finally, the aggregated data are delivered to the base station by the leader node in the vertical chain.

Fig. 2 shows data transmission in EECRP. As shown in **Fig. 2**, nodes c6, c16, c26, c36, c46, c56, c65, c75, c85 and c95 are chain heads and form a vertical chain to send their data to the base station. Node c6 is the leader of the vertical chain because it has the shortest distance from the base station. Chain heads send their data to node c6 through the vertical chain and node c6 aggregates and transmits the data to the base station.

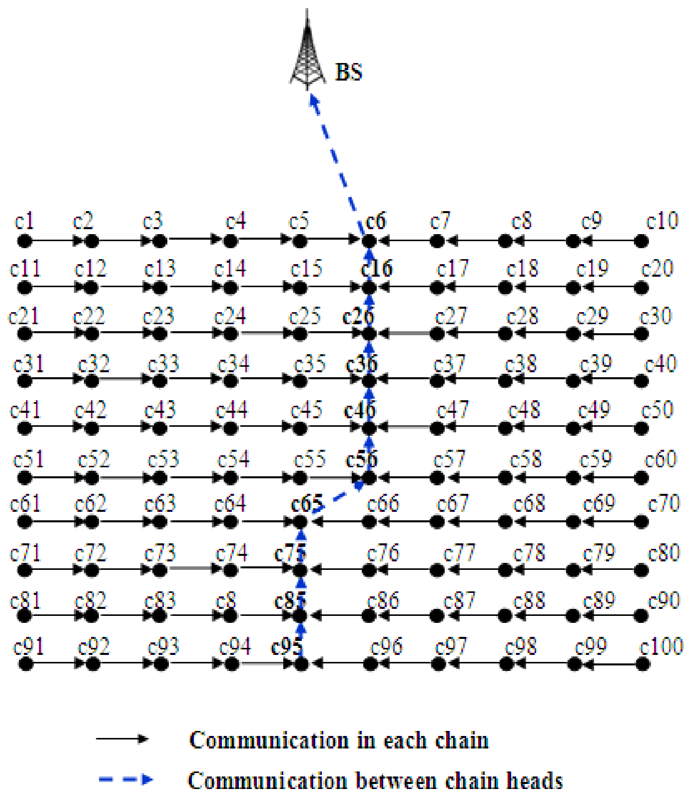

Fig. 2. Data transmission in EECRP

Fig. 3 shows the pseudo code of EECRP.

```
The network is divided into a set of strips
Each node is located in strip x, 1≤x≤ k
Strip (i) ⟵ x

Phase 1: Set up phase
for  i=1: N
    Node i sends (location_i , RE_i ) to BS
    CHSV_i ⟵ RE_i / dist^2_{to heigher CH}        // BS computes CHSV of all nodes
end
if   CHSV_i  > CHSV of all nodes in each strip
    Chainheads(i) ⟵ True      // BS selects node i as chain head
end
if  Chainheads(i)=True
    if Strip(i)=1
        Leader(i) ⟵ True
    else
        Leader(i) ⟵ False
    end
BS creates a chain among sensor nodes in each strip from farthest node to nearest node from node i
end
BS sends chains and chain head ID to all nodes

Phase 2: Data transmission phase
for i=1: N
    if Chainheads(i)= True
        Node i in each chain generates 2 tokens and sends them to two end nodes in the chain
    end
end
for i=1: N
    if  Chainheads(i)= False
        Node i aggregates its data with the data of previous node
        Node i sends aggregated data and token to the next node in the chain
    end
end
for i=1: N
    if  Chainheads(i) =True
        if  Leader(i) = False
            Node i aggregates its data with the data of previous CH node in the chain of CHs
            Node i sends aggregated data to the next CH node in the chain of CHs
        end
    end
end
for i=1: N
    if  Chainheads(i) =True
        if  Leader(i) = True
            Leader i aggregates its data with the data of previous CH node in the chain of CHs
            Leader i sends aggregated data to the BS
        end
    end
end
```

Fig. 3. Pseudo code of the proposed algorithm

5. Simulations and Results

To evaluate performance of EECRP discussed in the previous section, these simulations are presented by MATLAB and its performance is compared with other protocols such as LEACH, PEGASIS and ECCP. This section describes performance metrics, simulation setup and simulation results.

5.1 Performance Metrics

The following metrics are used to capture performance of the proposed routing approach and to compare it with other protocols.

- Network lifetime: The performance metrics used to evaluate the network lifetime include First Node Dies (FND), Half of the Nodes Alive (HNA) and Last Node Dies (LND) [23].
- Energy consumption: The total energy consumed by the nodes in receiving and sending the data packets.
- Average energy consumed per round: Average energy consumed by the nodes in receiving and sending the data packets in each round.
- Total number of data messages received in the base station: It is the total number of data packets received in the base station.
- Transmission delay: It is the time interval from the moment when the data packets are transmitted to the moment when the base station receives these data packets.
- Energy × delay: For many applications, in addition to minimizing energy, it is also important to consider the delay incurred in gathering sensed data. Energy × Delay metric presents schemes that attempt to balance the energy and delay cost for data gathering in wireless sensor networks [24].

5.2 Simulation Setup

The simulations are carried out with a random network topology with 100 sensor nodes randomly distributed in the monitoring area with the size of 100 m × 100 m. The base station locations are varied at (0,0), (50, 50) and (50,175). The basic parameters for these simulations are shown in **Table 1**.

Table 1. Simulation parameters

Parameters	Value
Network size	(0,0) to (100,100)
Number of nodes	100
Base station location	(0,0),(50,50), (50,175)
Data packet size	1000 Bytes
Control packet size	40 Bytes
Initial energy of nodes	0.4 J
Height of each strip (h)	10 m
P_{Ch}	0.1
Cluster radius r	15 m
E_{elec}	50 nJ/bit
E_{fs}	100pJ / bit /m^2
ε_{amp}	0.0013 pJ / bit /m^4
E_{DA}	5 nJ/bit/signal

5.3 Simulation Results

5.3.1 Network Lifetime

Fig. 4 shows the total number of nodes that remain alive over the simulation runs with base station location at (50,175). **Fig. 5**, **Fig. 6** and **Fig. 7**, respectively, indicate performance comparison of the network lifetime using FND, HNA and LND metrics with different locations of the base station. **Table 2** shows number of rounds when 1%, 50% and 90% of nodes die. It is clear from **Fig. 4**, **Fig. 5**, **Fig. 6**, **Fig. 7** and **Table 2** that EECRP has better performance than LEACH and PEGASIS in terms of network lifetime with different locations of the base station. The time of the last node to die in EECRP is longer than other protocols and sensor nodes remain alive for longer time. This is mainly because most of the nodes transmit to their nearest neighbors in the chain. For selecting the chain heads in horizontal chains, EECRP also considers residual energy of nodes and distance of nodes from the header of upper level that eliminats the need for reselecting leader of the vertical chain.

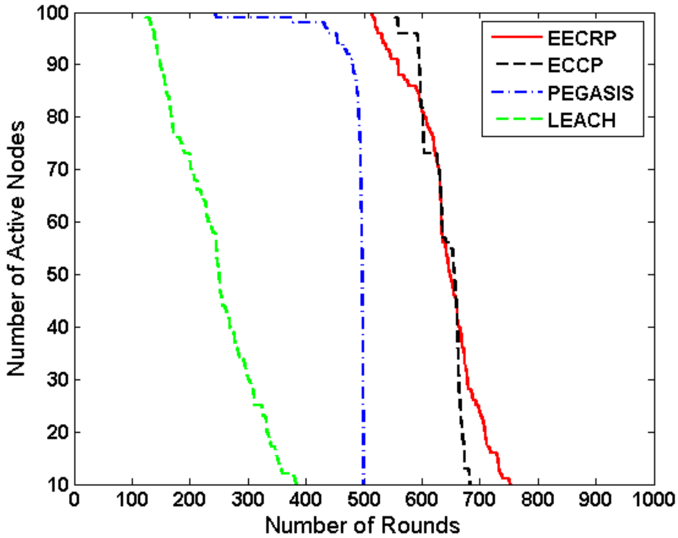

Fig. 4. Number of active nodes per round with BS location at (50,175)

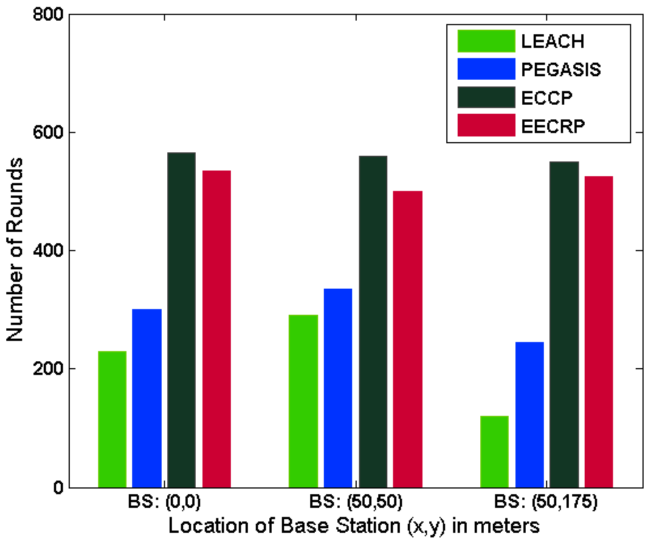

Fig. 5. Performance comparison of the network lifetime using FND metric with BS locations at (0, 0), (50, 50) and (50,175)

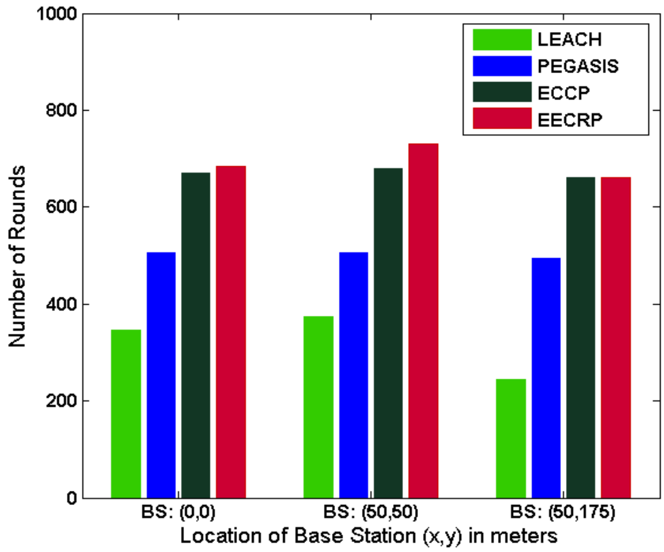

Fig. 6. Performance comparison of the network lifetime using HNA metric with BS locations at (0, 0), (50, 50) and (50,175)

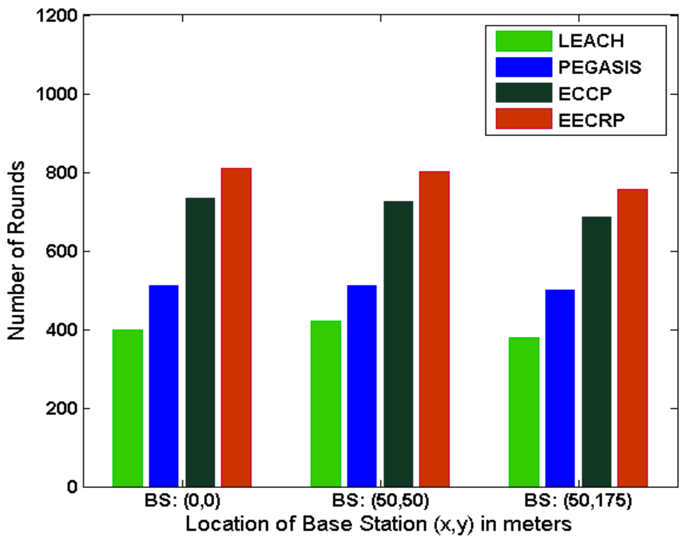

Fig. 7. Performance comparison of the network lifetime using LND metric with BS locations at (0, 0), (50, 50) and (50,175)

Table 2. Number of rounds when different proportions of nodes die

BS location	Protocol	No. of rounds (1%)	No. of rounds (50%)	No. of rounds (90%)
(0,0)	LEACH	231	350	400
	PEGASIS	300	505	516
	ECCP	568	669	737
	EECRP	530	681	812
(50,50)	LEACH	287	375	425
	PEGASIS	334	512	525
	ECCP	555	687	725
	EECRP	505	747	800
(50,175)	LEACH	125	247	381
	PEGASIS	247	495	500
	ECCP	550	637	687
	EECRP	525	637	762

The simulation results show that:

- Under FND metric, EECRP extends network life time approximately 129.4% and 76.6% compared with LEACH and PEGASIS, respectively, and reduces network life time approximately 6.7% compared with ECCP with base station location at (0,0).
- Under FND metric, EECRP extends network life time approximately 75.9% and 51.2% compared with LEACH and PEGASIS, , respectively, and reduces network life time approximately 9% compared with ECCP with base station location at (50,50).
- Under FND metric, EECRP extends network life time approximately 320% and 112.5% compared with LEACH and PEGASIS, respectively, and reduces network life time 4.5% compared with ECCP with base station location at (50,175).
- Under HNA metric, EECRP extends network life time approximately 94.6%, 34.8% and 1.8% compared with LEACH , PEGASIS and ECCP, respectively, with base station location at (0,0).
- Under HNA metric, EECRP extends network life time approximately 99.2%, 45.9% and 8.7% compared with LEACH , PEGASIS and ECCP, respectively, with base station location at (50,50).
- Under HNA metric, the network life time of EECRP is almost the same as ECCP and EECRP extends network life time approximately 158.1%, 28.8%, compared with LEACH and PEGASIS, respectively, with base station location at (50,175).
- Under LND metric, EECRP extends network life time approximately 103.1%, 57.6% and 10.1% compared with LEACH, PEGASIS and ECCP,respectively, with base station location at (0,0).
- Under LND metric, EECRP extends network life time approximately 88.2%, 52.4% and 10.3% compared with LEACH , PEGASIS and ECCP, respectively, with base station location at (50,50).
- Under LND metric, EECRP extends network life time approximately 100.1%, 52.5% and 10.9% compared with LEACH, PEGASIS and ECCP, respectively, with base station location at (50,175).

5.3.2 Energy Consumption

Fig. 8 demonstrates the energy consumed by all nodes during the simulation runs with base station location at (50,175). **Fig. 9** and **Table 3** show the average energy consumed per round with different locations of the base station. It is obvious that EECRP uses less energy compared with other protocols with different locations of the base station. LEACH consumes more energy because the cluster heads collect data from sensor nodes and transmit the data directly to the base station while, in EECRP, most of the nodes transmit only to their nearest neighbors in the chain. Moreover, instead of data transmision by multiple chain heads directly to the distant base station, only one chain head transmits data to the base station.

EECRP has better performance than PEGASIS. This is mainly because the chains in EECRP have smaller length than the single chain in PEGASIS, which reduce the amount of data to be aggregated and propagated along the chain and resulte in more savings in the energy consumption of the nodes. EECRP also has better performance than ECCP, which is mainly due to higher cluster formation overhead in ECCP when a sensor node dies in the cluster. Because of the cluster formation in ECCP, a lot of control messages are exchanged among sensor nodes.

The simulation results show that:

- EECRP is approximately 102.4%, 59.3% and 18.8% better than LEACH, PEGASIS and ECCP in terms of average energy consumption, respectively, with base station location at (0,0).
- EECRP is approximately 90%, 57.4% and 10% better than LEACH, PEGASIS and ECCP in terms of average energy consumption, respectively, with base station location at (50,50).
- EECRP is approximately 95.5%, 49% and 4.6% better than LEACH, PEGASIS and ECCP in terms of average energy consumption, respectively, with base station location at (50,175).

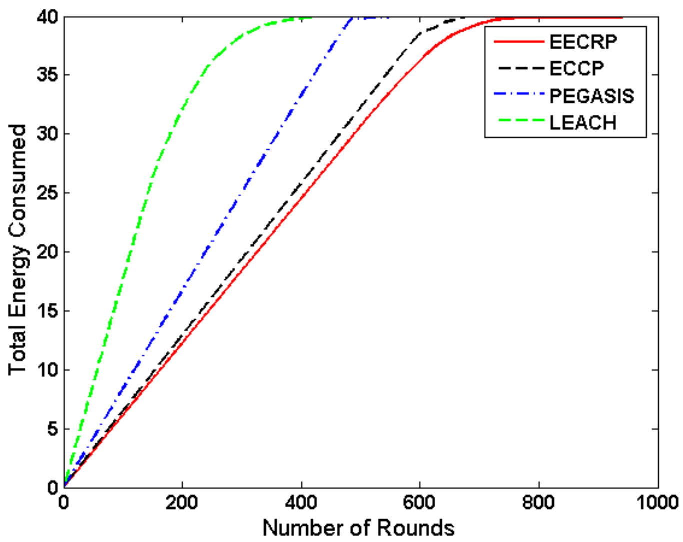

Fig. 8. Total energy consumption of the network with BS location at (50,175)

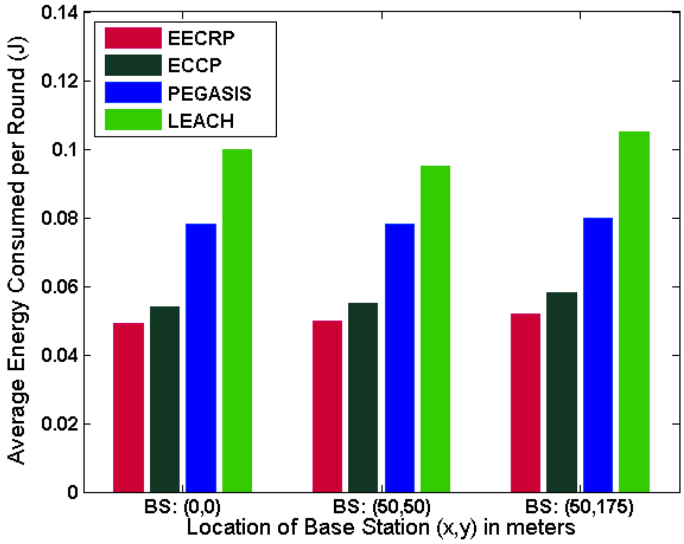

Fig. 9. Average energy consumed per round with BS locations at (0, 0), (50, 50) and (50,175)

5.3.3 Transmission Delay

Fig. 10 and **Table 3** show transmission delay of different routing protocols with different locations of the base station. Transmission delay of EECRP is almost the same as LEACH. EECRP is approximately 400%, and 40% better than PEGASIS and ECCP in terms of transmission delay, respectively, with different locations of base station. This is mainly due to the chains in EECRP have smaller length than the chain in PEGASIS and the chains in ECCP and smaller length of each chain in EECRP solves the problem of excessive delay experienced by distant nodes in the chains.

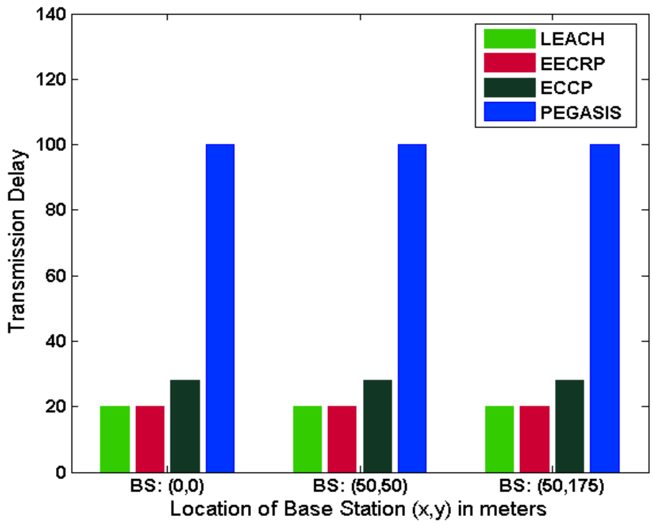

Fig. 10. Transmission delay with BS locations at (0, 0), (50, 50) and (50,175)

5.3.4 Energy × Delay

There is a trade off between energy spent per round and delay; energy×delay is an appropriate metric to optimize per round of data gathering in wireless sensor networks [24]. Fig. 11 shows energy × delay during a round in different routing protocols with different locations of the base station. Table 3 gives the results for energy cost, delay cost and energy×delay cost for LEACH, PEGASIS, ECCP and EECRP. It is clear that EECRP has better performance than LEACH, PEGASIS and ECCP in terms of energy × delay. ECCRP can meet both requirements for a prompt-response and energy-saving applications.

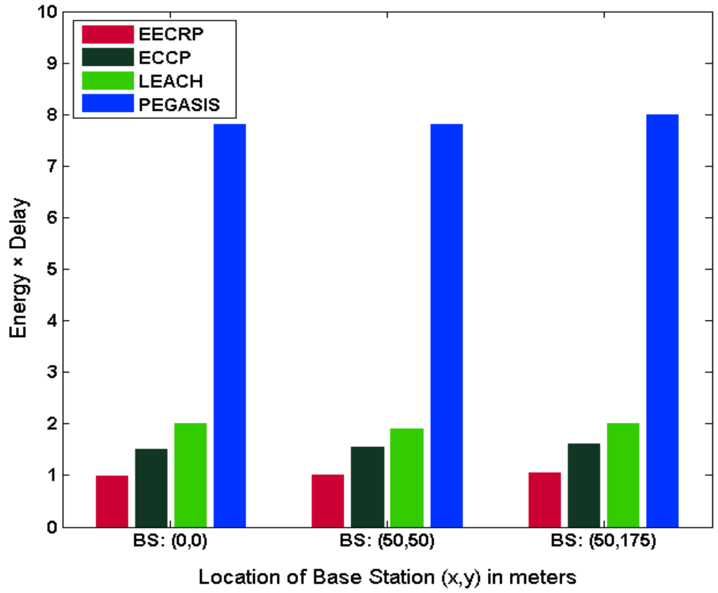

Fig. 11. Energy × Delay per round with BS locations at (0, 0), (50, 50) and (50,175)

Table 3. Energy cost, delay cost and energy × delay cost for LEACH, PEGASIS, ECCP and EECRP

BS location	Protocol	Average Energy	Delay	Energy × Delay
(0,0)	LEACH	0.1	20	2
	PEGASIS	0.0787	100	7.8
	ECCP	0.0587	28	1.65
	EECRP	0.0494	20	0.99
(50,50)	LEACH	0.095	20	1.9
	PEGASIS	0.0787	100	7.8
	ECCP	0.055	28	1.54
	EECRP	0.050	20	1
(50,175)	LEACH	0.105	20	2.1
	PEGASIS	0.080	100	8
	ECCP	0.0562	28	1.58
	EECRP	0.0537	20	1.07

The simulation results demonstrate that:

- EECRP is approximately 102%, 687% and 66.6% better than LEACH, PEGASIS and ECCP in terms of energy × delay, respectively, with base station location at (0,0).
- EECRP is approximately 90%, 680% and 54% better than LEACH, PEGASIS and ECCP in terms of energy × delay, respectively, with base station location at (50,50).
- EECRP is approximately 96.3%, 647% and 47.6% better than LEACH, PEGASIS and ECCP in terms of energy × delay, respectively, with base station location at (50,175).

It is clear from **Table 3** that EECRP reduces energy consumption, transmission delay and energy × delay compared with LEACH, PEGASIS and ECCP with different locations of base station. In summary, the proposed protocol attempts to balance the energy and delay cost for data gathering in wireless sensor networks and reduces the energy × delay cost compared with LEACH, PEGASIS and ECCP.

5.3.5 Total Number of Data Messages Received in the Base Station

Fig. 12 and **Fig. 13** show the number of data messages received in the base station with base station location at (50,175). **Fig. 14** and **Table 4** shows the total number of data messages received in the base station with different locations of the base station.

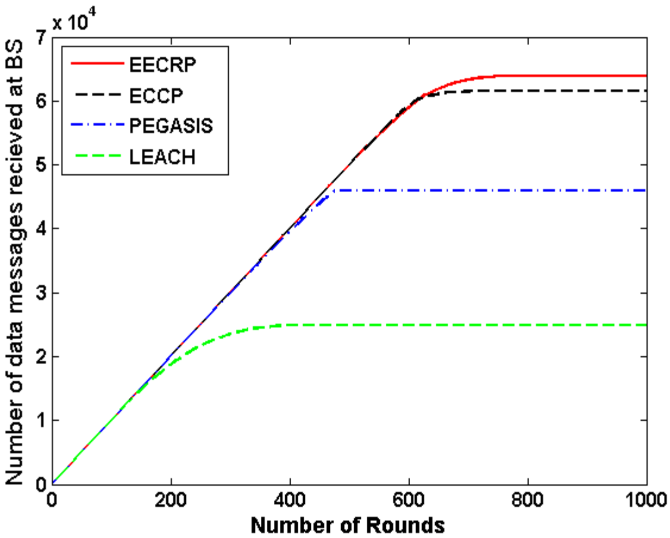

Fig. 12. Number of data messages received in the base station over round with BS location at (50,175)

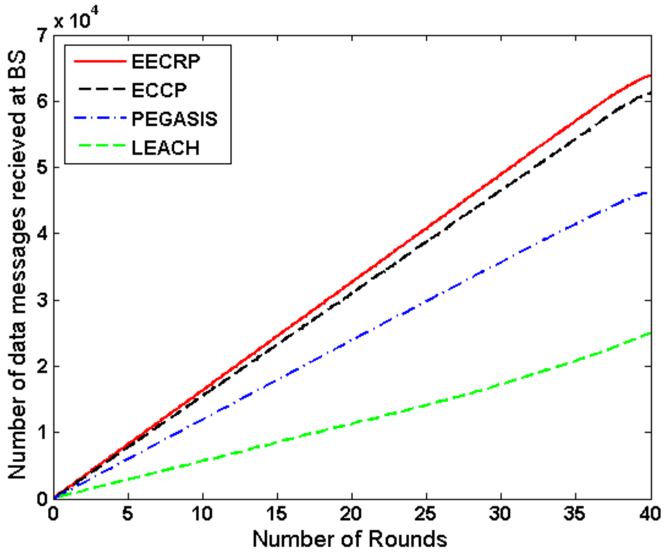

Fig. 13. Number of data messages received in the base station over energy with BS location at (50,175)

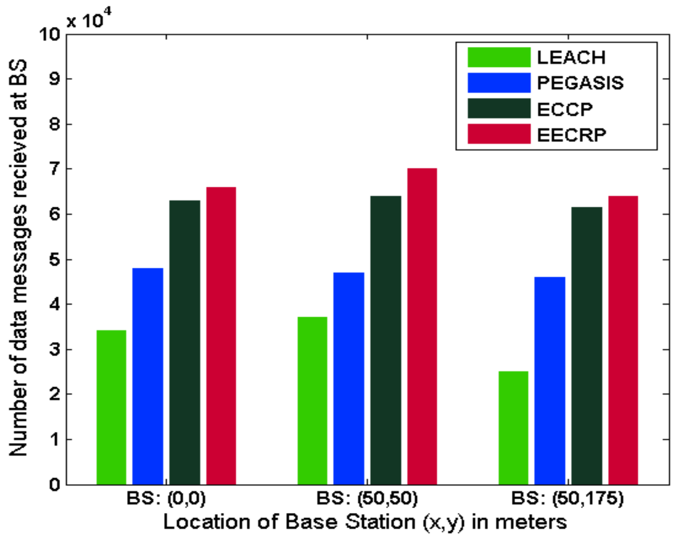

Fig. 14. Total number of data messages received in the base station with BS locations at (0, 0), (50, 50), and (50,175)

Table 4. Total number of data messages received in the base station with different locations of the base station

Protocol	BS location (0,0)	BS location (50,50)	BS location (50,175)
LEACH	3.44×10^4	3.74×10^4	2.5×10^4
PEGASIS	4.87×10^4	4.75×10^4	4.69×10^4
ECCP	6.31×10^4	6.37×10^4	6.12×10^4
EECRP	6.56×10^4	7×10^4	6.38×10^4

It is clear from **Fig. 12**, **Fig. 13, Fig. 14** and **Table 4** that the total number of data messages received in the base station in EECRP is greater than those in LEACH, PEGASIS and ECCP since EECRP reduces energy consumption in the network and increases the network lifetime.

The simulation results demonstrate that:

- EECRP increases the number of data messages received in the base station approximately 90.7%, 34.6% and 4% compared with LEACH, PEGASIS and ECCP, respectively, with base station location at (0,0).
- EECRP increases the number of data messages received in the base station approximately 87.2%, 47.4% and 9.8% compared with LEACH, PEGASIS and ECCP, respectively, with base station location at (50,50).
- EECRP increases the number of data messages received in the base station approximately 155.2%, 36% and 4.2% compared with LEACH, PEGASIS and ECCP, respectively, with base station location at (50,175).

6. Conclusion

In this paper, we have proposed an Energy Efficient Chain based Routing Protocol (EECRP) for wireless sensor networks. The main goal of EECRP is to minimize energy consumption, transmission delay and especially energy × delay metric. EECRP can meet both requirements for a prompt-response and energy-saving applications. EECRP organizes sensor nodes into a set of horizontal chains and a vertical chain so that each sensor node receives from a previous neighbour and transmitts to the next neighbour. Furthermore, EECRP improves the data transmission mechanism from the chain heads to the base station via constructing a chain among the chain heads. By chaining the nodes in the network, EECRP offeres the advantage of small transmit distances for most of the nodes and thus helps them to be operational for a longer period of time by conserving their limited energy. Simulation results demonstrate that the proposed protocol significantly outperformes LEACH, PEGASIS and ECCP in terms of network lifetime, energy consumption, number of data messages received in the base station, transmission delay and especially energy × delay.

References

[1] N. Aslam, W. Phillips, W.Robertson and Sh. Sivakumar, "A multi-criterion optimization technique for energy efficient cluster formation in wireless sensor networks," *Information Fusion*, vol. 12, Issue 3, pp. 202-212, July, 2011. Article (CrossRef Link)

[2] D. Tu, D. Zhang, M. Guo and Y. Shen, "Energy Efficient Transmission Distance Adjustment under Non-uniform Distributed Wireless Sensor Networks," in *Proc. of Int. Conf. on Communications and Mobile Computing (CMC'2010)*, pp. 490 – 495, April 12-14, 2010. Article (CrossRef Link)

[3] P.J. Chuang, Sh.H. Yang, and Ch.Sh. Lin, "Energy-Efficient Clustering in Wireless Sensor Networks," in *Proc. of 9th Int. Conf. on Algorithms and Architectures for Parallel, ICA3PP 2009*, vol. 5574, pp. 112-120, June 8-11, 2009. Article (CrossRef Link)

[4] Y. Jin, L.Wang, Y. Kim and X.Yang, "EEMC: An energy-efficient multi-level clustering algorithm for large-scale wireless sensor networks," *Computer Networks*, vol. 52, Issue 3, pp. 542–562, 2008. Article (CrossRef Link)

[5] P. Saini and A. K. Sharma, " Energy Efficient Scheme for Clustering Protocol Prolonging the Life Time of Heterogeneous Wireless Sensor Networks," *International Journal of Computer Applications*, vol. 6, no.2, pp. 30-36, September, 2010. Article (CrossRef Link)

[6] Y. Qian, J. Zhou, L. Qian, and K. Chen, "Prolonging the Lifetime of Wireless Sensor Network

Via Multihop Clustering," in *Proc. of 6th Int. Conf. on Next Generation Tele traffic and Wired/Wireless Advanced Networking*, vol. 4003, pp. 118-129, May 29 - June 2, 2006. , Article (CrossRef Link)

[7] J. Jabari Lotf, M. Nozad Bonab and S. Khorsandi, "A Novel Cluster-based Routing Protocol with Extending Lifetime for Wireless Sensor Networks," in *Proc. of 5th IFIP Int. Conf. on wireless and optical communications networks*, pp. 1- 5, May 5-7, 2008. Article (CrossRef Link)

[8] Yu. Chen, and Yi. Chen, "An Energy Efficient Clustering Algorithm Based on Residual Energy and Concentration Degree in Wireless Sensor Networks," in *Proc. of the Second Symposium International Computer Science and Computational Technology (ISCSCT '09),* pp. 306-309, December 26-28, 2009. Article (CrossRef Link)

[9] F. Tang, M.Guo, M.Yanqin Yang, D. Zhang and Y. Wang, "Wireless Mesh Sensor Networks in Pervasive Environment: A Reliable Architecture and Routing Protocol," in *Proc. of the 36th Int. Conf. on Parallel Processing Workshops (ICPPW'2007),* pp. 72, September 10-14, 2007. Article (CrossRef Link)

[10] D Zhang, Z. Yang, V. Raychoudhury, Z. Chen and J. Lloret, "An Energy-Efficient Routing Protocol Using Movement Trends in Vehicular Ad hoc Networks," *The Computer Journal*, published online: March 2013. Article (CrossRef Link)

[11] W. Heinzelman, A. Chandrakasan and H. Balakrishnan, "Energy-efficient communication protocol for wireless microsensor networks," in *Proc. of the 33rd Hawaii Int. Conf. on System Sciences (HICSS'00)*, January, 2000. Article (CrossRef Link)

[12] W. Heinzelman, A. Chandrakasan and H. Balakrishnan, "An application-specific protocol architecture for wireless microsensor networks," *IEEE Transactions on Wireless Communications*, vol. 1, Issue 4 , pp. 660-670, 2002. Article (CrossRef Link)

[13] S. Lindsey and C. Raghavendra, "PEGASIS: power-efficient gathering in sensor information systems," in *Proc. of IEEE Aerospace Conference*, vol. 3, pp.1125–1130, March 9-16, 2002. Article (CrossRef Link)

[14] A. Manjeshwar and D.P. Agrawal, "TEEN: a protocol for enhanced efficiency in wireless sensor networks," in *Proc. of the 1st Int. Workshop on Parallel and Distributed Computing Issues in Wireless Networks and Mobile Computing*, pp. 2009-2015, April, 2001. Article (CrossRef Link)

[15] A. Manjeshwar and D.P. Agrawal, "APTEEN: a hybrid protocol for efficient routing and comprehensive information retrieval in wireless sensor networks," in *Proc. of the 16th Int. Parallel and Distributed Processing Symposium*, pp. 195-202, April 15-19, 2002. Article (CrossRef Link)

[16] . Bajaber and I. Awan, "Energy efficient clustering protocol to enhance lifetime of wireless sensor network," *Journal of Ambient Intelligence and Humanized Computing*, vol. 1, no. 4, pp. 239-248, June, 2010. Article (CrossRef Link)

[17] O. Younis and S. Fahmy, "HEED: A hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks," *IEEE Transaction Mobile Computing*, vol.3, Issue 4, pp.366-379, 2004. Article (CrossRef Link)

[18] H.Y. Lee, K.O. Lee, H.L. Lee and A. Kusdaryono, "CBERP: Cluster Based Energy Efficient Routing Protocol for Wireless Sensor Network," in *Proc. of the 12th Int. Conf. on Networking, VLSI and Signal Processing*, pp. 24-28, February 20-22, 2010. Article (CrossRef Link)

[19] F. Tang, I. You , S. Guo, M. Guo and Y. Ma, "A chain-cluster based routing algorithm for wireless sensor networks," *Journal of Intelligent Manufacturing*, vol. 23, Issue 4, pp. 1305-1313, August, 2012. Article (CrossRef Link)

[20] B. Zarei, M. Zeynali and V. Majid Nezhad, "Novel Cluster Based Routing Protocol in Wireless Sensor Networks," *IJCSI International Journal of Computer Science Issues*, vol. 7, Issue 4, no. 1, pp. 32-36, July, 2010. Article (CrossRef Link)

[21] R. Sheikhpour, S. Jabbehdari and A. khademzadeh, "A Cluster-Chain based Routing Protocol for Balancing Energy Consumption in Wireless Sensor Networks," *International Journal of Multimedia and Ubiquitous Engineering*, vol. 7, no. 2, pp. 1-16, April, 2012. Article (CrossRef Link)

[22] R.Sheikhpour and S. Jabbehdari, "An Energy Efficient Cluster-Chain based Routing Protocol for

Time Critical Applications in Wireless Sensor Networks," *Indian Journal of Science and Technology*, vol. 5, no. 5, pp. 2741-2749, May, 2012. Article (CrossRef Link)

[23] M.J. Handy, M. Haase and D. Timmermann, "Low Energy Adaptive Clustering Hierarchy with Deterministic Cluster-Head Selection," in *Proc. of 4th IEEE Int. workshop on Mobile and Wireless Communications Networks*, pp. 368-372, September 9-11, 2002. Article (CrossRef Link)

[24] S. Lindsey, C. Raghavendra and K. M. Sivalingam, "Data Gathering Algorithms in Sensor Networks Using Energy Metrics," *IEEE Transaction on parallel and distributed systems*, vol. 13, no.9, pp.924-935, September, 2002. Article (CrossRef Link)

Razieh Sheikhpour received the M.Sc. degree in computer engineering from the department of computer engineering, North Tehran Branch, Islamic Azad University in 2012. She is member of International Association of Engineers (IAENG) and Young Researchers and Elites Club of Islamic Azad University. She has published over 20 papers in National and International conferences and international journals. Her research interests include Information Security, ISO/IEC 27000, COBIT, ITIL, IT Governance, IT Management and Wireless Sensor Networks.

Sam Jabbehdari currently working as an assistant professor at the department of Computer Engineering in IAU (Islamic Azad University), North Tehran Branch, in Tehran, since 1993. He received his both B.Sc. and M.S. degrees in Electrical Engineering Telecommunication from K.N.T (Khajeh Nasir Toosi) University of Technology, and IAU, South Tehran branch in Tehran, Iran, in 1988, through 1991 respectively. He was honored Ph.D. degree in Computer Engineering from IAU, Science and Research Branch, Tehran, Iran in 2005. He was Head of Postgraduate Computer Engineering Department IAU-North Tehran Branch during 2008-2010. He also has written "Advanced Topics in Computer Networks" book in Persian Language (Tehran, Classic, 2009). His current research interests are Scheduling, QoS, MANETs, Wireless Sensor Networks and Grid Computing Systems