An Improved Chain-based Hierarchical Routing Protocol for Wireless Sensor Networks

Samah Alnajdi, Fuad Bajaber
Department of Information Technology
Faculty of Computing and Information Technology
King Abdulaziz University, Jeddah, Kingdom of Saudi Arabia
alnajdisamah@gmail.com, fbajaber@kau.edu.sa

***Abstract*—In recent years, wireless sensor networks (WSNs) applications became widely used in different domains such as military, industrial and environmental monitoring, disaster management, healthcare, ...etc. However, there are many challenges in WSNs that affect the networks performance and one of the main challenges is limitted energy of sensor nodes. Due to this limitation in energy, routing considered as a critical issue for WSNs and many routing protocols have been proposed to improve the energy consumption by sensor nodes. In this paper, we propose an efficent hierarchical routing protocol based on multi chain clustering using improved existing methods including optimal-K model and K-means clustering method. Based on simulation by MATLAB, the proposed protocol showed improvement in comparision to other protocols in term of network lifetime and the average energy consumption.**

Keywords—WSNs; routing protocols; pegasis; chain clustering; k-means; energy consumption; network lifetime;

I. INTRODUCTION

Wireless sensor networks (WSNs) consist of a large number of low-cost and lightweight sensor nodes that capable of sensing and collecting data from the deployment area “sensing field” to be sent wirelessly to a super node called the base station (BS) in turn to take the appropriate actions. Each node consists of a sensor for one or more specific task, a micro controller for processing, a radio module for sending data via a wireless medium, and power supplier that is usually difficult to recharge due its deployment situations.

Different types of routing protocols were employed in the WSNs throughout the years and they are divided into three types based on the network structure: flat, hierarchical, and location-based routing protocols. In flat routing protocols, each nodes in the network performs the same task as it sense the data from the field then transmit it to the BS by itself, normally using flooding. This type of routing in WSNs is effective in the small-scale networks. While in location-based routing protocols, data transmitted depending on the geographical positions using real time applications[1]. For hierarchical routing protocols (HRP), sensor nodes classified to perform different tasks and involved in multi-hop communication.

In addition, hierarchical routing protocols (HRP) aim at maintaining an efficient energy consumption by sensor nodes to prolong the network lifetime by assigning different roles to the nodes where nodes could be classified either a cluster head (CH) that its main function is data transmission between other CHs or with the BSs, or as member node (MN). The MNs are the rest of nodes that performs the data sensing and transmit to their CH[1].

Based on the clustering techniques, the main categories of hierarchical routing protocols are: cluster-based, chain-based and tree-based protocols[2]. In cluster- based protocols, one or multiple nodes selected to be a CH while the other nodes set as member nodes of the cluster whit the closest CH. Some known cluster-based protocols include LEACH, HEED, and TEEN [3]–[5]. For the Tree-Based protocols, the principal concept that all sensed data sent only from children nodes to its parent nodes. An example of a tree-based protocol is DRINA[6]. While in chain-based routing protocols, nodes arranged in a chain-like topology where some node selected to function as a CH and transmit collected data to the BS. Chain-based clustering show more promising than the other methods in terms of energy consumption.

Moreover, chain-based routing protocols use different algorithms during the various phases as in the chain formation process, the leader nodes selection, data aggregation transmission, and also in choosing the number of the chains in case of multi-chain routing.

In this paper, we will propose a multi-chain routing protocol, and since number of chains, or clusters in general, affects the overall network performance we used an optimal K equation introduced by Amini et al. in[7]. For the chain formation process, an existing enhanced greedy algorithm deployed along with a fitted leader selection method that insures minimizing the energy consumption by sensor nodes.

A literature review of chain=based protocols presented in the following section. A detailed description of our proposed protocol presented in section III. The simulation along with the results are in section IV. Finally, the conclusion in section V.

II. LITERATURE REVIEW

Forming a chain topology including all sensor nodes in the area is an important step of routing before the data sensing and transmission start and in order to achieve better performance many parameters should considered such as the nodes energy, distance between nodes, nodes density, BS location, …etc. Therefore, many improvements proposed throughout the years and some of the important ones reviewed below:

A. Single Chain-Based Routing Protocols

The first protocol begins chain-based clustering was PEGASIS[8] by Lindsey and Raghavendra in 2002, they used the greedy approach in the chain formation process where each node connects to its nearest node that did not join the chain yet. Therefore, each node will have only two connections: the child node i.e. receives data from and the parent node i.e. transmits to it, and they take turns to be the leader of the round. However, even though the protocol showed better performance than other hierarchal protocols such as LEACH, there were many shortcomings including the long distance between nodes i.e. long link problem (LL), not considering the distance from leader node and BS which results in redundant data transmission, neither considering the residual energy of the leader node, huge transmission delay, …etc. To solve these problems in PEGASIS, other protocols such as IEEPB[9] and EAPHRIN[10] improved the chain formation algorithm.

In IEEPB, an enhanced greedy algorithm used where the comparison of distance occurs twice before any node join the chain. First, when the last node joined the chain search it is nearest, that did not join the chain yet, to ask them to join. Second, when the later node compare the distance to nodes already on the chain to connect to the closest one. The protocol allows each node to have more than only two connected nodes in order to reduce the LL problem. However, having more connections will increase the energy consumption by parent nodes.

Another different chain formation method, in EAPHRIN they proposed randomness in the chain formation where the end node connects to a random node that is located no farther than a distance threshold so that distances between neighbors do not exceed a reasonable distance.

In addition, Gupta and Saraswat[11] proposed another different chaining algorithm where nodes are ordered from farthest to closest to the BS and the first node in order searches and connects to its nearest node, with the constraint that it can only connects to a node which is above in ordering. Other improvements by theses protocols includes leader selection methods, where some important parameters considered such as the nodes residual energy, distance from BS, number of connections …etc.

However, the high transmission delay in the single chain routing led to a multiple chain routing proposals, where multiple chains formed using either the same or another chaining algorithms.

B. Multi Chain-Based Routing Protocols

In multi-chain routing protocols, the number of formed chains and the process of dividing nodes into groups to form those chains plays a huge part. One known protocol is EPEGASIS[12] proposed by Jung et al. in 2007 that applied concentric clustering for network division considering the location of the BS, which divides the field into several levels with the BS as the center and in each level a chain is formed using the greedy algorithm as in PEGASIS. Although it mainly improves the redundant data transmission problem, chains in EPEGASIS get longer as the levels get farther from BS which causes more delay in farther chains. Moreover, shorter life for sensor nodes in closer levels to the BS due the often responsibility of sending to BS. To solve the large size of farther levels in EPEGASIS, the CHIRON[13] protocol proposed applying the BeamStar technique[14] which still divides the field levels same way as in EPEGASIS but then each level is split into two halves so smaller groups are formed. Both protocol still used the greedy algorithm to form the chains.

Another protocol by Hadjila et al.[15] proposed forming multiple parallel chains in the direction of the BS and set the first node of each chain as the leader of their chain. Then, a main chain formed consist of all leader nodes to take the role of sending the aggregated data to the BS in turn. Nevertheless, the protocol has many shortcomings and one of them was the death of nodes occur faster in area nearest to the BS, therefore, a good coverage of entire area will be unavailable.

In this work, we will propose a protocol that solve some problems existing in the literature to achieve more efficient energy consumption and prolong the network lifetime.

III. THE PROPOSED PROTOCOL

A. Network Model

In our model, we assume a homogenous network as all the randomly distributed sensor nodes have equal properties and the BS fixed far from the sensing field.

For the energy radio model, the same model described in [16] and [7] is adopted in our work. In this model, to transmit *L* bits message a distance *d*, the radio expends:

$$E_T(L,d) = E_{elec} \times L + E_{amp} \times L \times d^n \quad (1)$$

to receive *L* bits message, in the model the radio expends:

$$E_R(L) = E_{elec} \times L \quad (2)$$

Where E_{elec} the energy dissipated per bit to run the transmitter or the receiver circuitry and E_{amp} the energy dissipation of the transmission amplifier depending on the distance to the receiver. In equation 1, if the distance between transmitter and receiver is less than a threshold the free space channel model is used where ($n = 2,\ E_{amp} = E_{fs}$); otherwise multipath fading channel model is used where ($n = 4,\ E_{amp} = E_{mp}$).

B. Multi Chain Efficient Routing Protocol (MCER)

In general, our proposed protocol MCER forms multiple chains on the sensor nodes level and another chain on the leader nodes level in order to forward collected data to the BS, as showed in Fig. 1. MCER goes through several stages to set up the routing protocol and start the data transmission.

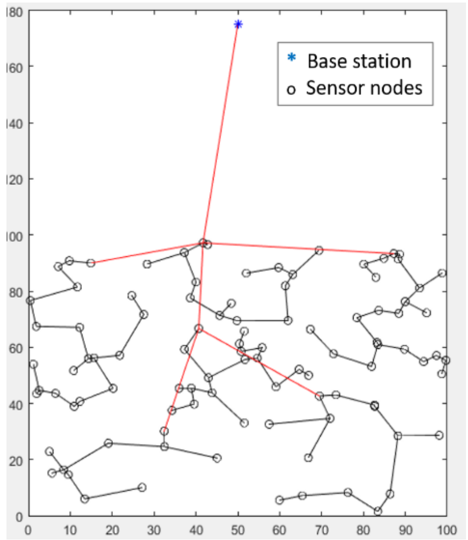

Fig. 1 A network simulation of the proposed protocol MCER

1) Number Of Chains (K) Selection

Deciding the optimum number of chains or clusters had been a major issue in hierarchal routing protocols as it directly affect the energy consumption by sensor nodes. The value of K usually is statically selected as in some protocols in the literature. In our work, we applied an analytical model derived by N. Amini et al. in [7] that dynamically calculate the optimal value of K based on the network model parameters. The analytical model is showed in equation 3.

$$k_{opt} = \sqrt{\frac{N \times E_{fs} \times M^2}{2\pi\left(E_{mp}\left(\frac{7 \times M^4}{180} + \frac{2}{3}M^2R^2 + R^4\right) - Eelec^{Rx}\right)}} \quad (3)$$

Where M is the side of the square sensing field, R the distance from the BS to the center of the sensing field. The result value of K changes throughout the network lifetime depending on number of alive nodes N.

2) Network Division

After selecting the optimum number of chains, MCER performs *k-means* clustering algorithm[17] in order to organize the nodes into K groups. The algorithm is centroid-based where at the end of the algorithm execution each node joins the group with nearest nodes. In case of a change in the K value, the network division process is re-executed.

3) Chain Formation

To connect the nodes in each group in a chain-like topology, MCER performs the enhanced greedy algorithm as in IEEPB. The algorithm works as follow:

a. The node farthest from the BS join the chain first and labeled as the end node of the chain

b. End node of the chain finds the nearest node that did not join the chain yet, and sets it as next node waiting to join the chain.

c. Next node compare distance between itself and nodes already on the chain and connects with the nearest node of them.

d. After joining the chain, the next node becomes the end node of the chain and steps b-d repeated until all nodes in the group join the chain.

In case of a node dies in a particular chain, only that chain reformed again in order to bypass the dead node, while the rest of K chains stay the same.

4) Leader Node Selection

The selection of leader nodes is based on two parameters. In each round, the node with smaller distance from the BS and more residual energy will be the leader of their chain.

5) Head Leader Node Selection

One of the K leader nodes selected in the previous stage will take the role as the head leader of the round that is responsible of sending to the BS. Then, a chain formed including all leader nodes for forwarding data between the leaders and transmitting to the BS.

6) Data Transmission

In each round, each sensor node performs data aggregation of their sensed and received data from their child nodes into one data packet to be sent to their parent node in the direction of their chain leader. The leader nodes of all K chains send the collected data to the head node following the leaders' chain

IV. SIMULATION AND RESULTS

For evaluation, we used MATLAB 2017a simulations to compare MCER with PEGASIS and IEEPB. The simulation parameters presented in Table 1. The results presented are the average of 10 times simulation.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Number of nodes (N)	100, 200, 300
Network size	100 * 100 m
BS location	(50,175)
Initial energy	0.5 J
E_{elec}	50 *nJ/bit*
E_{fs}	100*pJ/bit/m*^{2}
E_{mp}	0.0013*pJ/bit/m*^{4}
The threshold distance	$\sqrt{E_{fs}/E_{mp}}$
Data packet size	2000 bits
Energy of data aggregation	5 *nJ/bit*

In simulation of 100 nodes network, Fig. 2 shows that MCER operation continued for 1940 rounds with 3% improvement over IEEPB that operated for 1881 rounds and 16.6% over PEGASIS that stopped at 1664 rounds.

For 200 nodes network scenario, Fig. 3 shows the performance of MCER increased as expected and continued to 2222 rounds with 21% improvement over IEEPB. For PEGASIS, it gave similar performance as in 100 nodes scenario and lasts for 1663 rounds, on the other hand, IEEPB protocol network lifetime reduced 2.7% in comparison of 100 nodes scenario as it ends at 1831 rounds.

Moreover, Fig. 4 shows the network lifetime of 300 nodes network with the performance keeps improving in MCER as it continued for 2362 rounds with 32% improvement over IEEPB and 42% over PEGASIS that again resulted in similar performance as in 100 nodes and 200 nodes network. While in IEEPB case, the performance keeps affected negatively and the network died at 1785 rounds. This fell in IEEPB performance is due the high density of nodes which cause sensor nodes to have larger number of connections generated by the enhanced greedy algorithm.

By having multiple chains instead of a single chain, MCER protocol solved the problem of IEEPB as the multi chain approach controls the total number of nodes in each chain and provide lower density of nodes. Therefore, parent nodes will consume less energy on receiving data in MCER compared to IEEPB. Fig. 4 shows the average energy consumed in each round by all sensor nodes.

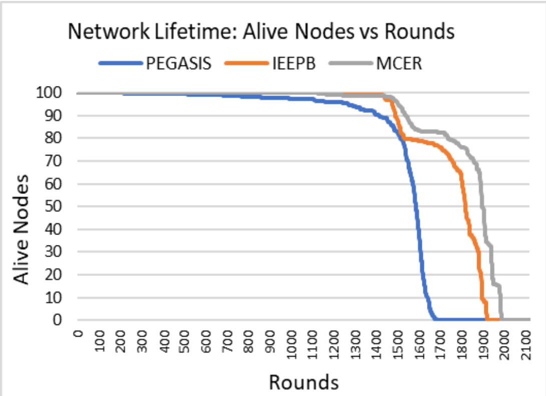

Fig. 2 The lifetime of 100 nodes network

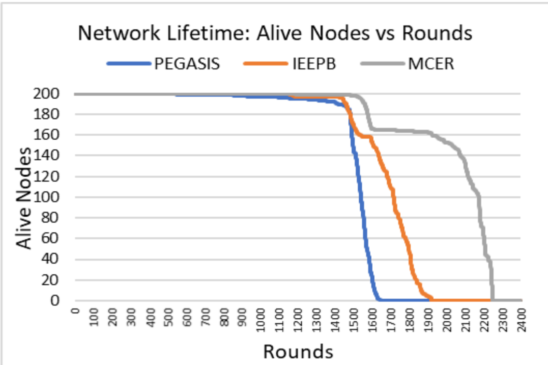

Fig. 3 the lifetime of 200 nodes network

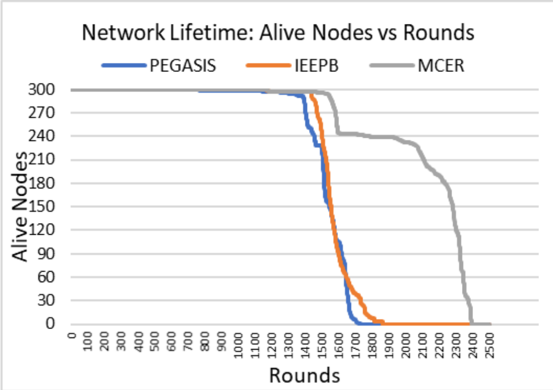

Fig. 4 The lifetime of 300 nodes network

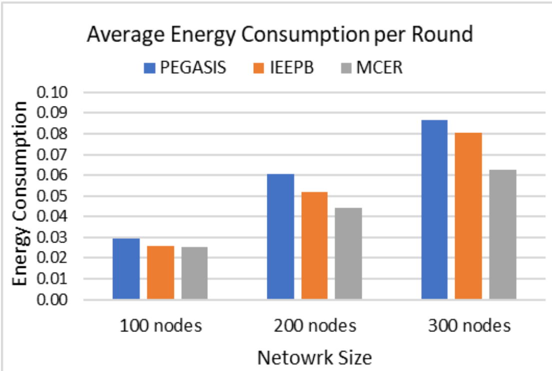

Fig. 5 Average Energy Consumption

V. Conclusion

An optimal-K based improved hierarchical routing protocol proposed in this paper that aims to improve the energy consumption and overall performance of WSNs by applying some improved algorithms including an enhanced greedy algorithm for chain formation and k-means clustering. The simulations showed that MCER improved the performance of WSNs as it prolonged the network lifetimes and reduces the energy consumption in comparison of PEGASIS and IEEPB protocols. Moreover, MCER solved the high energy consumption problem caused by high nodes density in IEEPB protocol.

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