Hierarchical Coordination for Data Gathering (HCDG) in Wireless Sensor Networks

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Abstract

A wireless sensor network (WSN) consists of large number of sensor nodes where each node operates by a finite battery for sensing, computing, and performing wireless communication tasks. Energy aware routing and MAC protocols were proposed to prolong the lifetime of WSNs. MAC protocols reduce energy consumption by putting the nodes into sleep mode for a relatively longer period of time; thereby minimizing collisions and idle listening time. On the other hand, efficient energy aware routing is achieved by finding the best path from the sensor nodes to the Base Station (BS) where energy consumption is minimal. In almost all solutions there is always a tradeoff between power consumption and delay reduction. This paper presents an improved hierarchical coordination for data gathering (HCDG) routing schema for WSNs based on multi-level chains formation with data aggregation. Also, this paper provides an analytical model for energy consumption in WSN to compare the performance of our proposed HCDG schema with the near optimal energy reduction methodology, PEGASIS. Our results demonstrate that the proposed routing schema provides relatively lower energy consumption with minimum delay for large scale WSNs.

Keywords: Energy Consumption, MAC Routing Protocols, Sensor Nodes, Wireless Sensor Network.

1. INTRODUCTION

There is a tremendous increase in the usage of wireless sensor networks (WSNs) for sensing and monitoring applications in the natural environment, industry, and military domains [1]. These networks usually consist of many low-power, low-energy, and low-cost sensor nodes with wireless communication links. The sensor nodes sense data from the nearby environment, receive data from other nodes , process the data, and send necessary data to other nodes or to the base station (BS) [2][3]. These networks are typically deployed in an Ad hoc manner where the participating nodes in a network share the same communication medium.

The sensor nodes are usually operated by batteries and left unattended after their deployment. This makes power saving scheme as one of the critical issues in WSNs as network should be considered to have a certain lifetime during which nodes should have sufficient energy for gathering, processing, and transmitting the information. Therefore, any protocol developed for sensor nodes communication should be designed to be extremely energy-efficient. The design of an energy-efficient protocol is an imminent problem to solve in WSNs [4].

WSNs usually consist of hundreds or even thousands of sensor nodes which may be sparsely distributed in non predefined remote locations. Thus, it becomes extremely difficult and computationally infeasible to recharge or replace the dead batteries of the network nodes. When sensor nodes in a WSN run out of energy they stop functioning as either data originators or data routers, causing a progressive deconstruction of the network. Therefore, one of the most stringent limitations that the development of a WSN faces today is the power consumption issues. In reality, a sensor node typically consumes the most of its energy during communication with the other nodes. However, lower energy expenditure takes place while performing sensing and data processing [5]. As a result, there is a great development of techniques recently requiring the elimination of energy inefficiencies at all layers of the protocol stack of sensor nodes.

More precisely, research on physical and data link layers of the protocol stack has been focused on system level energy awareness such as dynamic voltage scaling, radio communication hardware, low duty cycle issues, system partitioning, and energy aware MAC protocols [6]. At the network layer of protocol stack, the main objective is to setup the best energy-aware route from the sensor nodes to the BS to prolong the overall network lifetime. For these reasons, while routing protocols in traditional networks aim to accomplish a high quality of service, routing protocols in WSN are more concerned towards power consumption issues.

The routing protocols developed for WSNs are classified mainly as flat routing and hierarchical or cluster- based routing protocols [7] [8]. In the former, each node plays the same role (i.e., all active sensor nodes collaborate with each other to perform the sensing task). In the latter approach, however, sensor nodes are divided based on their geographical location and programmed to perform a different role with respect to their energy consumption. In this paper, we propose a hierarchical chain-based schema that introduces a new method for reducing the energy consumption. Our proposed HCDG scheme reduces the total energy consumption and provides relatively lower delay than the other hierarchical-based routing schemas such as LEACH [9] and PEGASIS [10].

The remainder of the paper is organized as follows: Section 2 provides an overview of the existing energy aware routing and MAC protocols for WSNs. In Section 3, we present our proposed HCDG routing schema. Section 4 provides analytical and simulation models for the proposed method to compare the performance with the PEGASIS and LEACH schemas. Finally, Section 5 concludes the paper with future work.

2. RELATED WORK

Energy aware routing is one of the hot research areas in WSNs. In general, routing protocols for WSNs can be classified according to their network structure as flat and hierarchical or location-based routing protocols. Specifically, routing protocols are classified into multipath-based, query-based, negotiation-based, quality of service (QoS)-based, and coherent-based routing protocols [2]. In flat networks, all nodes play the same role (i.e., each participating node aggregates data). In hierarchical protocols, nodes are divided into clusters where each cluster has one head node who is responsible to perform data aggregation. Since only head nodes can perform data aggregation, this reduces the energy consumption. Location-based protocols utilize position information to relay the data to the desired regions rather than the whole network [11]. For our proposed work, we use both hierarchical routing and location-based categories as a network structure.

Heinzelman et.al [9] introduced a hierarchical clustering algorithm for sensor networks, called Low Energy Adaptive Cluster – based protocol (LEACH). In LEACH the operation is divided into rounds. During each round, a set of nodes are selected as cluster–head nodes. Once selected, these cluster-head nodes cannot become cluster heads again for the next P rounds. Thereafter, each node has a $1/p$ probability of becoming a cluster head in each round. At the end of each round, each node which is not a cluster head selects the closest cluster head and joins that cluster to transmit data. In addition, cluster heads aggregate and compress the data and forward it to the BS. In this algorithm, the energy consumption distributes uniformly among all nodes whereas non–

head nodes turn off as much as possible. LEACH assumes that all nodes are in wireless transmission range of the BS which is not the case in many sensor nodes deployment algorithms. In each round, cluster heads comprise 5% of total nodes and use TDMA as a scheduling mechanism that makes it prone to long delays when applied to a large sensor network.

In [10] an enhancement over LEACH protocol was proposed. The protocol, called Power – Efficient Gathering in Sensor Information Systems (PEGASIS) a near optimal chain-based protocol for extending the lifetime of network. In PEGASIS, each node communicates with one of the closest neighbors by adjusting its signal power such that it can only be heard by the closest neighbor. Each node uses signal strength to measure the distance between its current location and the neighboring nodes to determine the node which is at the shortest possible distance. After chain formation, PEGASIS elects one of the nodes as a leader from the chain with respect to residual energy usage. Unlike LEACH [9], PEGASIS [10] avoids cluster formation and uses only one node in a chain to transmit the data to the BS rather than multiple nodes. This results in relatively lower overhead and the bandwidth requirements from the BS.

In COSEN [12], a chain oriented sensor network for collecting information was introduced where multiple lower chains are formulated exactly in the same manner as described in PEGASIS [10]. Each chain starts from the furthest node that includes a certain percentage of total nodes where the number of leaders equal to the number of formulated chains. Each leader from each chain collects and aggregates the data from its chain level and transmits this aggregated data to the higher level leader until it reaches to the BS. Introducing this hierarchical chain model in COSEN alleviated parallel data aggregation and hence achieved higher reduction in both energy and delay compared to PEGASIS and LEACH.

In [13], a new routing algorithm based on chaining structure was proposed. It was based on the same idea of chain formation as suggested by PEGASIS. However, it uses different criteria for selecting the next node in the chain formation process. PEGASIS adds the next node to the chain as the node closer to the last node in the chain. However, this method uses the distance between the next node and rest of the nodes that are currently part of the chain as criteria for selecting the next node. This new method of selecting the next node ensures that the total distance from any selected leader to other nodes in the chain is minimal and therefore offers relatively lower energy consumption than the original PEGASIS. Simulation results [13] show that this proposed method can reduce the total energy consumption more than the best traditional algorithms such as PEGASIS and LEACH with a factor of 34%.

Our proposed routing scheme differs from the existing solutions since we combine hierarchical chaining method for chain formation and selecting the next node based on the total distance to all other chain members. Our proposed method lowers the burden on the chain-leader by introducing a coordinator node who is responsible for collecting the data from the lower level chains and forwarding it to the leader node. Our proposed scheme makes parallel data gathering more feasible and thus provides relatively lower end-to-end delay than the other routing schemas that use the same hierarchical structures.

3. HIERARCHICAL COORDINATION AND DATA GATHERING SCHEME

One of the main objectives of the proposed scheme is to minimize both energy consumption and end-to-end delay which is required for data gathering in WSNs. Our proposed scheme is based on the same assumptions as described in [9] [10] [12]. Before we present the proposed scheme, it is worth mentioning some of our key assumptions.

1. We assume that the BS is located in a fixed place with a field of nodes deployed randomly where all nodes are considered to be stationary.

2. We assume that all sensor nodes encapsulate complete information about the network and each of them is able to adjust its transmission power such that it can only be heard by its closest neighbor.
3. We also assume that each node is capable to perform data aggregation from other nodes with its own data into a single packet.

4. Finally, we assume that sensor nodes and BS are homogeneous and have limited energy.

Our proposed HCDG scheme differs from [12] in both chain formation strategy and in proposing two role based coordination for each chain in the hierarchy. Our proposed schema, therefore, consists of three main phases: chain hierarchy formation, coordinators and leaders groups' selection phase, and data transmission phase.

3.1. Chain Hierarchy Formation

In this first phase of our proposed scheme, we use the next node selection criteria proposed in [13] and combined with [12] for hierarchical chain formation. In order to form the hierarchical chain, we start from the furthest node from the BS as illustrated in Algorithm 1. Next, we select the node which has the closest distance to the rest of nodes that are already exist in the chain. The chain formation reaches to its end once a certain percentage of total number of nodes in the field becomes members of that chain. We refer to this condition as chain saturation which indicates that a maximum number of nodes have associated with the chain and there is no need for extending the chain formation process. In other words, this percentage limits the number of

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Start from furthest node to the ***BS***

*/*initialization phase for chain and member IDs*/*

```
S1      CID= 0;      /*chain id*/
        MID=0;    /*member id initialization*/
        P=Percentage; /*node percentage for each chain*/
S2      Currentlocation= CID.member[MID].location

S3      while   (RemainingNodeCount>0) do:
S4          while (MID < P*TotalNodeCount) do:
S5              for (i=0 to RemainingNodesCount)
S6                  for     (j=0 to MID);
S7                          Totaldistance=Node[i].loc -CID.Member[j].loc
                    end for;
S8                              tmpDistance = Totaldistance/MID+1;
S9                      If      (tmpdistance < mindistanec) then
S10                             mindistance = tmpdistance;
S11                             CID.member[MID+1]= node[i];
                        end if
S12                 MID++;
S13                 RemainingNodesCount--;
S14                 Mindistance=Maxdistance;
                end for
            end while
S15             CurrentLocation=CID.member[MID].location
S16             CID++; MID=0;
        end while
```

Algorithm 1: Chain Hierarchy Formation chains in the hierarchy. For instance, 20 percent will produce 5 chains. The percentage of nodes in each chain should be proportional to the number of nodes in concentric distances from the BS. Very long chains result in more delays and more total energy consumption and the network operation will resemble that of PEGASIS. Shorter chains also result in longer delays but only for nodes farthest from the BS. The effect of the number of chains can be clearly seen in the equation presented in Section 4 of this paper. The chain hierarchy formation is done once setting up the network or when a certain percentage of nodes die.

3.2. Leader and Coordinator Candidates Selection Phase

In this second phase of our proposed scheme, members in each chain are divided evenly into two groups: leader candidates and coordinator candidates.

Leader Candidates: Leaders candidates are refer to those nodes from which a chain leader will be elected and is responsible for the following two tasks:

- Chain leader's first responsibility is to gather data from neighboring nodes that exist in the same chain.
- Chain leader's second responsibility is to transmit the aggregated data to the higher level chain coordinator or to the BS.

This group (i.e., the leader) will be selected by the members of the chain such that the selected leader should be at the closest distance to the BS or to the coordinator of the higher level chain.

Coordinator Candidates: In our proposed scheme, coordinator candidates refer to a group of nodes where a coordinator node will be elected and is responsible for collecting the aggregated data from each leader of the lower chain. Moreover, coordinators for the first chain are elected from those nodes that are at the furthest distance from the BS. Similarly, the coordinators for the lower level chains are elected from nodes that are at the furthest distance from the leader of the higher level chain.

Fig. 1 is an illustration of group selection after chain formation phase. The black color nodes indicate group of leader's candidates whereas gray color nodes represent coordinator candidates group. In addition, white color nodes indicate a selected coordinator in a certain round for each chain. Starting from Chain 0, black nodes are selected as leaders since they have minimal distance to the BS. The white node in chain 0 is the elected coordinator. Chain 1 calculates the distance from the coordinator of Chain 0 and selects the coordinators candidate group and the lead-

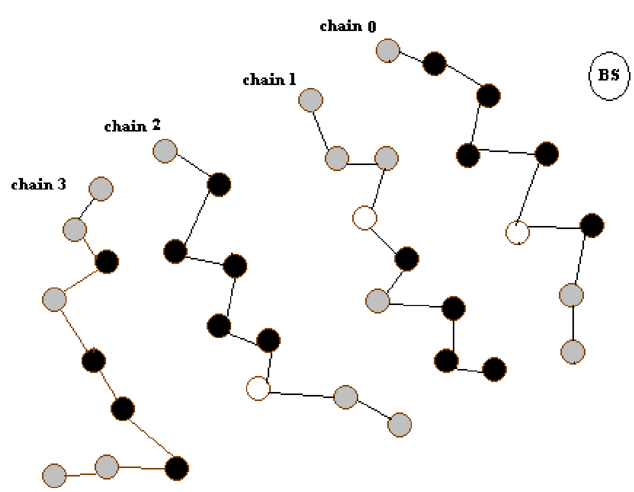

FIGURE1: Four chains sensor network deployment.

er's candidate group. Once the group selection is made, each chain coordinator keeps acting as a point of reference for lower chains to select candidate members for each group.

3.3. Data Transmission Phase

In this second phase of our proposed scheme, each node is assumed to have data available to be sent to the BS in a timely basis. In addition, each chain selects one leader and one coordinator based on the residual energy. Each sensor node will be informed by the location of the leader node using a token which is passed by the leader of the chain to all of its neighboring nodes. Nodes start receiving and sending the aggregated data packets in the direction of leader. Leader of each chain collects the data and send it to the coordinator of the higher chain.

3.4. Fairness, Energy Consumption, and Delay Reduction in HCDG

Groups of coordinators and leaders nodes are selected starting from the highest level chain. For each round, one leader and one coordinator node is selected from those groups according to the residual energy. For the lower level chains, groups are selected after every round whenever a new coordinator is selected in the hierarchy. As mentioned earlier, the higher level hierarchy changes typically after every round and imposes more processing for the nodes in lower level chains. However, this additional processing at lower level chains results in more fairness for the higher level chain nodes which performs more processing for data aggregation and direct communication with the BS.

The next node selection criteria for each chain will ensure total minimum distance between nodes. In the second phase, if the leader is comparatively at larger distance from the BS, it requires the leader to adjust its transmission to maximum power in order to reach the BS and transmit the aggregated data. The transmission at maximum power makes this node deplete energy faster than a closer leader even if it starts transmitting with comparatively higher energy. The above reason leads us to choose only those nodes as leader(s) that are closest to the BS in first chain. Similarly, in higher level chains, we choose leaders that are closest to the coordinator node. Another additional source of energy reduction in our work comes from the fact that the data gathering processing will be divided between the two nodes (i.e., the leader and the coordinator). The combination of leader and coordinator in our proposed scheme brings a degree of parallelism since both perform data gathering together at different levels of chain. For instance, a leader will start gathering its data from one side of its neighbors while the coordinator in the other side is collecting the data from the lower level. Our proposed scheme, therefore, yields comparatively lower delays than the other hierarchical routing schema such as PEGASIS [10].

4 ANALYTICAL MODEL FOR HCDG SCHEME

Firstly, in this section we present an analytical model to approximate the energy consumption for WSN. Secondly, we provide our critical analysis to analyze the performance of the proposed scheme with the other well known schemes. To support our analytical model, several numerical results will be presented in this section.

4.1. Energy Model

For the sake of analytical model, we use the same radio model as described in [10] [12] to compare the performance of proposed schema with the PEGASIS [10]. This model corresponds to the first order energy model where the parameters and values are used to evaluate the performance of all hierarchical routing schemas in WSNs. Table 1 shows the energy parameters and their corresponding values use for analytical model and performance evaluation. We use E_{Elec} as an energy consumption coefficient for the wireless transmission of a single bit whereas the parameter *k* represents the number of data bits to be transferred or received (i.e., the aggregated data packet bits). ε_{Amp} denotes the total energy required to amplify a single bit of a transmitted signal over the wireless medium. Finally, E_{Agg} indicates the combined amount of energy consumed for aggregating a nodes data packet with the received data packets.

Type	Parameter	Value
Transmitter Electronics	E_{Elec}	50nJ
Transmitt Amplifier	ε_{Amp}	100pJ/bit/ m^2
Aggregated Data Packet	*K*	2000 bit
Aggregation Energy	E_{Agg}	5nJ

TABLE 1: System Parameters Definition and Standard Values

Taking the above parameters into consideration, the transmission and reception energy consumption for each sensor node can be approximated as.

$$E_{T_x(k,d)} = E_{T_x}(k) + E_{T_x\_amp}(k,d)$$
$$E_{T_x(k,d)} = (E_{Elec} \times k) + (\varepsilon_{Amp} \times k \times d^2) \quad (1)$$

$$E_{R_x}(k,d) = E_{R_{x\_Elec}}(k) \cong E_{Elec} \times k \quad (2)$$

In both (1) and (2), E_{T_x} represents the total amount of energy used by a node to transmit the data where the subscript *d* represents the distance between the source and the target nodes. Moreover, E_{R_x} in (1) and (2) represents the total energy consumed by a single node to receive *k* bits of a data packet.

4.2. Energy Consumption Comparison

In PEGASIS [10], all nodes are arranged in one chain and only one node is selected as a head of the chain. The head node is responsible for aggregating the data from all neighboring nodes and transmitting it to the BS. We compare energy consumption for the three modes of operations with *N* nodes in both PEGASIS and our proposed HCDG Schema.

Energy for Transmission: In PEGASIS, total energy consumption for all nodes can be approximated as follows:

$$E = (N \times E_{Elec} \times k) + (\varepsilon_{Amp} \times k \times)\left[\sum_{m=1}^{N} \langle d_{m-1,m} \rangle^2\right] \quad (3)$$

In our proposed HCDG schema for *N* nodes with CN chains, we have $n = N/CN$ nodes per chain. All nodes except the leader in each chain transmits the data to its closest neighboring node with total energy equal to the total energy per chain multiplied by the number of chains. This can be formularized as

$$E = CN \times E_{CH} \quad (4)$$

Further elaborating (4) results

$$E = CN\left[\left(n \times E_{Elec} \times k\right) + \left(\varepsilon_{Amp} \times k\right)\sum_{m=1}^{n}\left\langle d_{(m-1,m)}\right\rangle^{2}\right] \tag{5}$$

Comparing (3) with (5), we can observe that they are equal if and only if $d_{(i,j)}$ is minimal in both. However, the selection criteria taken in our method is proved in [13] to produce smaller distances between nodes.

Energy Consumption for Receiving Data: In PEGASIS, each node receives data if it is an intermediate node. Based on that, the energy consumed by each receiving node can be approximated as follows:

$$E = (N-1) \times E_{Elec} \times k \tag{6}$$

In our proposed HCDG Schema, worst scenario is the same as in PEGASIS equation (6) where the last node in each chain is the leader for that chain and the first node in the next chain is the coordinator of that chain which makes our schema looks like a one chain schema.

For best case scenario, when the leader and the coordinator nodes are not the last or first nodes in the chain, the total energy consumed by each chain for receiving the data can be approximated as follows:

$$E_{CH} = \left(\frac{N}{CN}\right)\left(E_{Elec} \times k\right) \tag{7}$$

The last chain will have only $\frac{N}{CN} - 1$ *number of* received packets since there is no data to be received from lower chains. Taking this into consideration, the total energy for all chains can be approximated as:

$$\begin{aligned} E &= (CN-1)\left(\frac{N}{CN}\right)\left(E_{Elec}k\right) + \left(\frac{N}{CN} - 1\right)\left(E_{Elec} \times k\right) \\ E &= \left(E_{Elec} \times k\right)\left\langle N\left(\frac{CN-1}{CN}\right) + \left(\frac{N-CN}{CN}\right)\right\rangle \\ E &= \frac{N}{CN}\left(E_{Elec} \times k\right)\left\langle N-1\right\rangle \end{aligned} \tag{8}$$

Equation (8) is identically approximated as (6). From the above approximations, one can conclude that the energy consumed for receiving aggregated packets is the same as it is consumed in PEGASIS scheme.

Energy Consumption for Data Aggregation: In PEGASIS, for the best case scenario, all nodes perform data aggregation except the leaf nodes. Based on this, the total energy consumption can be approximated as:

$$E = (N-2) \times E_{Agg} \tag{9}$$

On the other hand, in our proposed HCDG schema, all nodes in each chain perform data aggregation except the leaf nodes. Taking this into consideration, one can approximate the total energy consumption for each chain as follows:

$$E_{CH} = \left(N \big/ CN - 2 \right) \times E_{Agg} \tag{10}$$

Based on (10), total energy consumed by the proposed HCDG schema for data aggregation can be approximated as follows:

$$\begin{aligned} E &= CN \times E_{CH} \\ E &= CN \times \left[\left(N \big/ CN - 2 \right) \times E_{Agg} \right] \\ E &= \left(N - 2 \times CN \right) E_{Agg} \end{aligned} \tag{11}$$

Comparing (9) and (11), one can observe that the proposed HCDG schema yields the lower total consumption in data aggregation operation compared to what is consumed by the PEGASIS scheme. Table 2 and Fig. 2 show a comparison of time consumed between the PEGASIS and the proposed HCDG scheme in data aggregating for one round of transmission in all nodes. The power consumption is measured in nano-joules (*nJ*) for both PEGASIS and the proposed HCDG routing schema.

***Energy Consumption When Transmitting to BS*:** In PEGASIS, all nodes in the chain takes turn to transmit the aggregated data to the BS. Based on that, one can approximate the energy consumption as follows:

$$E = \left(E_{Elec} \times k \right) + \left\langle \varepsilon_{Amp} \times k \times d^2 \right\rangle_{(i,\, BS)} \tag{12}$$

In each round of transmission, the distance between the BS and the head node varies substantially. Consequently, the total energy consumption for multiple rounds increases by increasing the distance and the elected furthest head will consume its energy faster than the other nodes.

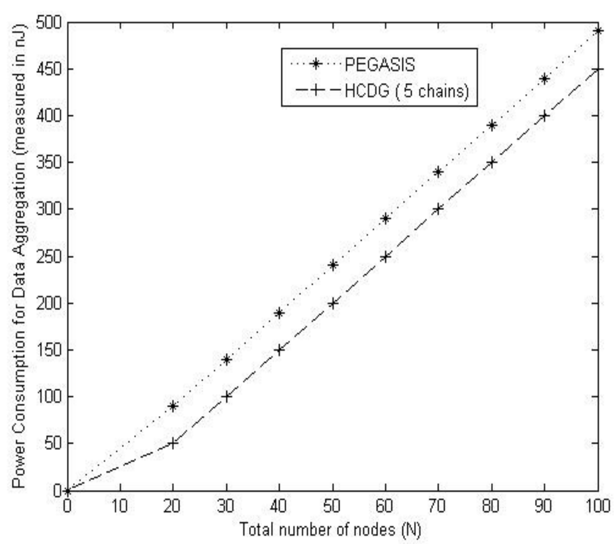

FIGURE 2: An illustration of total power consumption for data aggregation versus the total number of nodes (*N*).

	Power Consumption for Data Aggregation	
Total Nodes (N)	**PEGASIS**	**HCDG (5 chains)**
20	90nJ	50nJ
40	190nJ	150nJ
60	290nJ	250nJ
80	390nJ	350nJ
100	490nJ	450nJ

TABLE 2: Total Power Consumption for Data Aggregation versus Total Number of Nodes

On the other hand, in our proposed HCDG schema, only half of the nodes that exist in the closest chain to the BS are allowed to transmit the data. This hypothesis can be used to approximate the limits of both proposed HCDG and PEGASIS schemas for multiple rounds.

$$\begin{aligned} &Avg\left(d^2{}_{(i,\,BS)}\right) HCDG < \\ &Avg\left(d^2{}_{(i,\,BS)}\right) PEGASIS \end{aligned} \tag{13}$$

From all the above equations, we showed that our schema outperform PEGASIS in energy reduction for data transmission between nodes, data aggregation, and data transmission to the BS.

4.3. Delay Reduction

This section analyzes the best and worst cases delays performance of the proposed schema. For the sake of the performance evaluation and experimental verifications, we use the TDMA based scheduling with the proposed HCDG scheme.

Let t is the time unit required to transmit the data from one node to its immediate neighboring node. In PEGASIS, the worst case scenario is to have the head node as the last or the first node of the chain where the data will be sent to all N number of active nodes in order to reach the BS. Based on this argument, the total delay can be approximated as:

$$Delay = N \times t \tag{14}$$

On the other hand, the best case scenario is when we have the head node positioned exactly in the middle of the chain so that the data from both sides could be gathered in a parallel manner which results in a best case delay. If N is odd, the aggregated data from both sides arrives at the same time to the head. This implies that the head node needs to defer receiving the data from one side by a factor of one time unit. On the other hand, if N is even, the data from the longer side arrives in one time unit later than the shorter side. The head node adds another time unit to send to the BS. Based on the above argument, one can approximate the best case delay as follows:

$$Delay = \begin{cases} \left(\dfrac{(N-1)}{2} + 2\right) \times t \rightarrow if\ \ N\ \ is\ \ odd \\ \left(\dfrac{N}{2} + 1\right) \times t \rightarrow if\ \ N\ \ is\ \ even \end{cases} \tag{15}$$

In proposed HCDG schema, we use multiple chains that can be formalized as: *n =N/CN*. The worst case delay scenario is when the first node of the chain acts as the coordinator where as the last node acts as the leader. This configuration makes our worst case delay scenario similar to what is described for the PEGASIS. However, the probability of having this worst case delay is extremely small due to the group selection criteria we have used with the proposed HCDG scheme.

For the best case scenario, the leader and the coordinator nodes are located in the middle of the chain where both of them are one node apart from each other. This configuration is true for each chain. Based on the above specification, delay for the lowest level chain which will have only one leader and coordinator node can be approximated as follows:

$$Delay = \begin{cases} \left(\frac{(n-1)}{2} + 2 \right) \times t \rightarrow if \;\; n \; is \; odd \\ \left(\frac{n}{2} + 1 \right) \times t \rightarrow if \;\; n \; is \; even \end{cases} \qquad (16)$$

In the higher level chain, leader will keep busy in gathering the data from one side and will be waiting to receive the data from the coordinator side. Coordinator, on the other hand, waits to receive the data from the lower level chains. Once Coordinator node receives the data from the lower level chain, it needs one extra time unit to send it to the leader node. The leader node also needs one additional time unit to send it to the upper level chain. In this manner, each chain adds two time units to the delay incurred from the lowest level chain. The above arguments can be used to derive an approximation for the best case delay for both even and odd number of nodes.

$$Delay = \begin{pmatrix} 2 \times (CN - 1) \\ + \left(\frac{n-1}{2} + 2 \right) \end{pmatrix} * t \rightarrow if \;\; n \; is \; odd \qquad (17)$$

$$Delay = \begin{pmatrix} 2 \times (CN - 1) \\ + \left(\frac{n}{2} + 1 \right) \end{pmatrix} * t \rightarrow if \;\; n \; is \; even \qquad (18)$$

Both Table 3 and Fig. 3 demonstrate a comparison between the PEGASIS and the proposed HCDG schema for the best case delay scenario. For the sake of experimental verifications, different sizes of networks are used with number of chains (i.e., CN=5, *n* = N/CN). A significant de-

Total Nodes (N)	Lowest Delay PEGASIS	Lowest Delay HCDG (5 chains)
50	26 t	14t
100	51t	19t
200	101t	29t
300	151t	39t
400	201t	49t

TABLE 3: Delay Analysis versus Total Number of Nodes for PEGASIS and HCDG Schemas

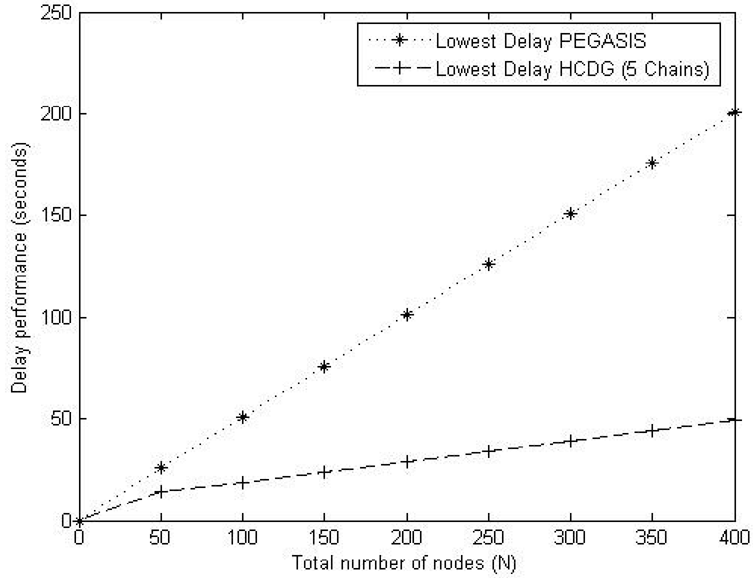

FIGURE 3: An illustration of delay performance versus the total number of nodes (*N*). The delay is measured in seconds for both PEGASIS and the proposed HCDG routing schema. A significant performance gain can be evidenced for the proposed HCDG scheme

lay reduction was obtained by using our proposed HCDG schema when compare to the PEGASIS for denser networks.

5. CONCLUSION

In this paper, we presented a new routing schema, hierarchical Coordination for Chain Based Data Gathering (HCDG) for WSN. The proposed HCDG schema introduced a new concept of leaders and coordinators nodes in a multichain hierarchical sensor network. In order to support the proposed HCDG schema, this paper provided a complete analytical model to approximate the energy consumption for wireless sensor nodes. Our numerical results demonstrate that the proposed HCDG schema can reduce energy consumption by a large magnitude when compared to the PEGASIS which was originally designed to outperform the well known LEACH method. Also, the analytical model and the results showed that the proposed HCDG schema substantially reduces the delay when compared to delay incurred in PEGASIS for denser WSN.

However, the numerical data which we have collected based on the proposed analytical model gives only a clue of the actual performance of the proposed HCDG schema. This is mainly due to the fact that the random generation of the wireless sensor nodes is hard to model using the mathematical equations presented in this paper. In future, we plan to design and conduct larger-scale experiments and simulation for better understanding of the energy consumption of the proposed HCDG schema and their correlations with different chain formation criteria and other design alternatives for selecting leaders and coordinators nodes.

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