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A Novel Biased Energy Distribution (BED) Technique for Cluster-Based Routing in Wireless Sensor Networks

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Abstract - This paper presents the impact of utilizing a biased energy distribution (BED) scheme for clustering sensor networks. In clustering sensor networks, some of the nodes are elected as aggregators and they compress the data from their cluster members before sending the aggregated data to the sink. Existing clustering routing protocols assume that all the nodes are provided with equal amount of energy but this shortens the network lifetime and makes the network unstable. This paper proposes a solution prioritizing the network into higher and lower energy nodes. The aim of this approach is to ensure well balanced energy consumption in order to maximize network lifetime. It is shown by simulation that the proposed technique exhibits better performance when compared to existing clustering routing techniques in terms of throughput, network lifetime and energy consumption.

Index terms*:* Sensor network, clustering routing techniques, biased energy distribution, network prioritization.

I. INTRODUCTION

Almost Contemporary advancements in nanotechnology, micro-electro-mechanical systems (MEMS) technology, radio technology, digital electronics, digital signal processing and wireless communications have immensely contributed to the design of miniaturized and smart sensors. This technological progress made the concept of wireless sensor networking feasible and it created a lot of possibilities in using sensor nodes for monitoring remote events [2], [3], [4]. Wireless sensor network applications include tracking wildlife migration, monitoring infernos, reconnaissance and surveillance, weather observation and pervasive computing [1], [2], [3], [5]. Wireless sensor networks comprises of numerous nodes that cooperatively operate in order to attain a global task. The architecture of a sensor network comprises of a sink and sensor nodes. Communication is carried out among the nodes to relay valuable data to the sink. This communication can be affected by the time-criticality and accuracy of the desired data and other pertinent factors such as scarce energy resources and limited sensing, computing and communication capabilities [1], [3], [4].

Sensor nodes can be deployed in geographical areas where it can be extremely difficult to recharge the in-built batteries or even replace the nodes, hence it is the goal of every sensor network design to increase the longevity of the network. One of the most energy-consuming operations in sensor networking is the reception and transmission of data. An energy-efficient solution for this is to use low duty cycling by strategically turning on and off the radio of sensor nodes based on the demand to carry out a sensing task. Other means of conserving energy via minimizing redundant data transmission are data compression, data fusion, data aggregation and data filtering [2], [3], [4].

A number of routing algorithms have been recently designed for wireless sensor networks [5], [6]. However, designing energy-aware routing protocols is challenging as a result of the inherent energy constraints of the sensor nodes. Researchers are currently investigating and developing clustering routing protocols with the aim of solving the energy conservation problem [3], [7], [8], [9], [10], [11], [12]. It has been stated in the literature that though clustering may introduce overhead in terms of network configuration and maintenance, clustering routing protocols still perform better and they possess more desirable energy minimization capability when compared to flat network topologies [3], [4].

Existing clustering routing protocols adopt an unbiased energy distribution scheme where the sensor nodes have equal amount of energy. However, this approach shortens the network lifetime because the network becomes unstable once the first node dies and hence more energy is consumed. This paper presents a solution by using a technique that prioritizes the network into higher and lower energy nodes. The aim of this is to ensure well balanced energy consumption in order to maximize network lifetime. The remainder of the paper is organized as follows: In Section 2, related works are discussed. In Section 3, the mechanism of the proposed biased energy distribution (BED) scheme is discussed. In Section 4, the simulation results are presented and discussed. In Section 5, the conclusion of this work is presented together with possible areas of further research.

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II. RELATED WORKS

A The Low-Energy Adaptive Clustering Hierarchy (LEACH) is an adaptive and self-organizing protocol that minimizes energy consumption in wireless sensor networks [2], [7]. The underlying idea behind LEACH is the use of randomized rotation of aggregators so that energy dissipation is shared evenly among all participating sensor nodes [2], [3], [4], [6]. Energy consumption is minimized through the randomized rotation of the aggregator. Network lifetime is enhanced and transmission of redundant data is curtailed as a result of performing data aggregation. Inter-cluster and intra-cluster collisions are minimized by the use of negotiation and TDMA MAC scheme.

LEACH faces scalability problems when it is used in a dense network scenario because it uses single-hop communication which is ineffective and energy consuming for long distance communications. The use of dynamic clustering introduces extra overhead such as aggregator advertisements that can adversely diminish the energy conserved. Data collection is centralized and periodic hence periodic data transmissions can rapidly drain the limited amount of energy. Due to non-uniform distribution of aggregators, it is possible that aggregators will be unfairly concentrated in a network segment. Therefore, some nodes will suffer by not having aggregators in their locality.

TEEN (Threshold-Sensitive Energy-Efficient Sensor Network) and APTEEN (Adaptive Periodic Threshold-Sensitive Energy-Efficient Sensor Network) were proposed in [8] and [9] respectively for time-critical applications. TEEN is a protocol developed to respond to abrupt changes in the sensed attributes [3], [4], [5]. The soft and hard threshold reduces the number of transmissions by preventing redundant data transmission which leads to energy conservation. APTEEN offers a wide range of flexibility by allowing users to set the count time interval and minimize energy consumption.

A limitation of TEEN is the inability to communicate if the thresholds are lost. TEEN is inapplicable for networks where periodic readings need to be delivered to the sink because the attributes’ values might not reach the threshold at all. One of the drawbacks is that message can get lost if aggregators are not in each other’s transmission radius.

A common drawback of both TEEN and APTEEN are the complexity and overhead related to (1) cluster formation and (2) threshold management and query handling.

Geographic Adaptive Fidelity (GAF) is a protocol originally developed for mobile ad hoc networks (MANETs) but found useful for sensor networks [3], [5], [10]. The fundamental idea behind GAF is that for each grid area, a node serves as a leader to convey data to other nodes but unlike other cluster routing protocols, these leader nodes do not perform data aggregation [4], [6], [10]. This protocol preserves energy by discovering equivalent nodes and turning off idle nodes. As a result, GAF can considerably increase network longevity as the number of sensor nodes increases.

One of the drawbacks of this algorithm is the use of GPS technology which is energy-expensive and costly. The algorithm determines travel time in order to support mobility. This might be difficult or nearly impossible to estimate in sensor networks where nodes are deployed in areas with unfavorable environmental conditions.

Periodic, event-driven and query-based (PEQ) protocol is designed for networks which are used as surveillance systems operating under critical conditions. The basic idea behind PEQ is the use of hop level of nodes to minimize redundant data transmission [3], [4], [11]. PEQ uses multi-hop communication which is simple and effective for long distance communication in a large network scenario. Low latency is ensured and energy consumption is minimized by using optimal path routing. Reliability is maintained by using an ACK-based repair mechanism. A major limitation is flooding and broadcasting of configuration and subscription messages. This leads to redundant transmission and reception of data and mismanagement of scarce energy resources.

Clustering Periodic, Event-driven and Query-based (CPEQ) protocol is a cluster-based approach where sensor nodes with more energy are selected as aggregators. Aggregators form clusters and cluster members communicate with their respective aggregators [3], [4], [11]. This algorithm possesses all the strengths of PEQ, namely; low energy consumption, support for low latency; support for reliability and simplicity. Another advantage of this algorithm is the aggregation of data which saves energy by reducing repetitive data transmission. However, a major limitation is the redundant transmission and reception of packets in the configuration process. In a highly-dense network scenario, high amount of energy will be wasted in the transmission of and listening to unwanted or unnecessary packets.

Energy Efficient Inter-cluster Communication based (ICE) algorithm is a protocol designed for periodic, event-driven and query-based networks. Message routing is accomplished via the help of aggregators and nodes nearest to each other within two adjacent clusters. As a result, data transmission is carried out via short transmissions [3], [4], [12]. This protocol has the benefits of CPEQ and PEQ, namely; data aggregation, support for reliability, simplicity and support for low latency. Energy is conserved as a result of short-range transmissions using nearest neighbors. Load balancing, network longevity and fault tolerance is ensured through the use of multi-path routing. Notifications are prioritized and least-cost path is used to provide Quality of Service (QoS).

A limitation is the inability to form a logical line for clustering. This means no nearest neighbors will be discovered and data transmission will be negatively affected. Redundant transmission and reception of packets are highly likely to occur. The management and maintenance of the entire network can be costly and difficult in a scenario where the sensor nodes in the wireless sensor network are mobile and the network is growing in size.

III. PROPOSED BED SCHEME

The proposed Biased Energy Distribution (BED) scheme is an improvement on existing clustering routing protocols. In the proposed BED scheme, a fraction of the entire sensor nodes is provided with higher energy than the remainder of the sensor nodes. Consequently, the sensor nodes in the network are categorized into higher and lower energy nodes. Higher energy nodes are a percentage (*m* %) of the total sensor nodes (*n*) and they have *k* times more energy than lower energy nodes. By adopting this approach, the network will be able to take full advantage of the additional energy resources of the higher energy nodes by favoring them to be elected as aggregators a factor of *k* times more than lower energy nodes. As a result of this, the performance of the network now depends on the choice and control of the parameters *m* and *k*.

Configuration of the Network: The wireless sensor network needs to be properly configured before being used to monitor and gather data from the environment. The initial configuration of the network commences when the sink floods the entire network with discovery packets. At the end of this phase, each node determines the number of hops it takes to reach the sink and locates the nearest neighboring nodes for forwarding data to the sink. The discovery packet for this configuration process has an additional field that contains the percentage of higher energy nodes (*m* %) and the corresponding factor of energy gain (*k*).

Selection of Aggregators: The aggregator selection algorithm is an improved version of the one employed in existing clustering routing protocols. After the network configuration process, sensor nodes can become an aggregator with a specified probability *p*. Each higher energy nodes becomes an aggregator *k* times every round compared to the lower energy nodes. This is accomplished by letting each node generate a random number between 0 and 1 and if this number is less than the probability *p*, the node will request the amount of energy of its neighboring nodes by sending them energy request packets. The neighboring nodes then respond with energy reply packets that contain their IDs and amount of energy. Based on the energy levels, higher and lower energy nodes are determined. Nodes with more energy are thus selected as aggregators by sending them aggregator select packets with special priority given to higher energy nodes in the selection process. The aggregator selection algorithm is repeated at specified intervals.

Configuration of Clusters: The newly elected aggregator is responsible for notifying its nearest neighbors that it is the new aggregator. In this way, each aggregator forms a cluster of nodes. The cluster configuration algorithm is achieved through the broadcasting of aggregator notify packets. When a node receives an aggregator notify packet, it stores the ID of the transmitting node in its routing table in order to know the route to the aggregator for forwarding data through the discovered route. If a node receives aggregator notify packets from more than one aggregator, the node will join the cluster that is closer to the aggregator. Each node can become an aggregator with a probability P_{opt}. And every node must become an aggregator once every ($1 / P_{opt}$) rounds. It is assumed that the non-elected nodes are a member of set F in the past ($1 / P_{opt}$) rounds and each sensor node chooses a random number between 0 and 1 inclusive [7], [10]. If this is lower than the threshold for node n, $T(n)$, the sensor nodes become an aggregator. The threshold $T(n)$ is given by:

$$T(n) = \begin{cases} \dfrac{P_{opt}}{1 - P_{opt}[r \times mod(1/P_{opt})]} & if\ n \in F \\ 0 & otherwise \end{cases} \tag{1}$$

Assume nodes are uniformly and randomly distributed in an N × N region. There are i clusters. On average there would be (n / i) nodes per cluster, one aggregator and (n / i) – 1 non-aggregator. In this protocol, cluster configuration is done with respect to the threshold of energy level between the higher energy nodes and the lower energy nodes. The initial energy for lower energy nodes is E_0, and for higher energy nodes, $E_{high} = G (C + K) \bullet E_0$.

Where K is the desired increment, C is the unit of incremental factor for the energy gain and G is the scaling factor for the energy gain. The election probability P_{opt} remains the same. However, the total initial energy of the system is increased by the introduction of higher energy nodes as shown in the equation below:

$$n \cdot E_0(C - m) + n \cdot m \cdot G \cdot E_0(C + k) = n \cdot E_0[C(1 + m \cdot G) - m(1 - k \cdot G)] \tag{2}$$

From the above equation it is observe that the overall energy of the network is increased by a fraction of C and the new epoch of the system is ($1 / P_{opt}$) • ($C (1 + m \bullet G) – m (1 – k \bullet G)$). By letting P_{low} and P_{high} to denote probability of becoming lower and higher energy nodes respectively Hence we have:

$$P_{low} = \frac{P_{opt}}{C(1 + m \cdot G) - m(1 - k \cdot G)} \tag{3}$$

$$P_{high} = \frac{P_{opt} \cdot G \cdot (C + k)}{C(1 + m \cdot G) - m(1 - k \cdot G)} \tag{4}$$

To guarantee that the sensor node must become aggregator as earlier assumed above, a new threshold for the election processes must be defined, referring back to equation (2) above. The corresponding thresholds $T\,(\,n_{low}\,)$ and $T\,(\,n_{high}\,)$ for lower and higher energy nodes respectively are:

$$T(n_{low}) = \begin{cases} \dfrac{P_{low}}{1 - P_{low}[r \times mod(1/P_{low})]} & if\ n_{low} \in F' \\ 0 & otherwise \end{cases} \qquad (5)$$

From the above we have $n \times (\,c - m\,)$ lower energy nodes, which ensures that the assumption in equation (1) is exact. Where F^{1} is the set of lower nodes that has not become aggregator in the past $(\,1 / P_{low}\,)$ round r. As for higher energy nodes, the threshold is as expressed below:

$$T(n_{high}) = \begin{cases} \dfrac{P_{high}}{1 - P_{high}[r \times mod(1/P_{high})]} & if\ n_{high} \in F'' \\ 0 & otherwise \end{cases} \qquad (6)$$

$n \times m$ higher energy nodes is obtained; with F^{11} as the set of high nodes that has not become aggregator in the past $(\,1 / P_{high}\,)$ round r.

From equation (3) and (4), the average number of aggregator per round will be:

$$n \cdot (C - m) \cdot P_{low} + n \cdot m \cdot P_{high} = \frac{P_{opt}[n(C - m) + n \cdot m \cdot G(C + k)]}{C(1 + m \cdot G) - m(1 - k \cdot G)} \qquad (7)$$

As a result of employing a biased energy distribution scheme, energy consumption is better regulated which leads to a better network performance as shown in the simulation.

Data Transmission to the Aggregators: Whenever a node detects an event in the monitoring environment, the sensed data will be forwarded to the respective aggregator for that cluster. The data forwarding algorithm simply lets nodes use the information in their routing table to find paths to the sink. The aggregators are treated as sinks by their respective cluster members. After receiving the data from its cluster members, the aggregator compresses the data to reduce the amount of packets to be forwarded to the sink.

Data Transmission to the Sink: After receiving data from the cluster member sensor nodes, the aggregator needs to forward this data to the sink. As aforementioned, the aggregator compresses the data to reduce the amount of packets to be forwarded to the sink. Due to the energydemanding nature of data compression, the BED scheme favors higher energy nodes to be used as data aggregators in order to maintain load balancing and ensure fair utilization of energy resources. The communication between aggregators and the sink is multi-hop transmission. This means that an aggregator sends its data via the shortest route to the sink that was configured during the initial network configuration phase.

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IV. SIMULATION RESULTS

In this research work, a clustered wireless sensor network is simulated in a field of dimensions 100m by 100m using MATLAB and OMNET++. The total number of sensors is n = 100. The higher and lower energy nodes are randomly and uniformly distributed over the sensor network field while the sink is situated in the center of the network field. The initial energy of a lower energy node is set to E_0 = 0.5 Joules. The energy dissipated by the transceiver, data aggregator and amplifier are respectively 50nJ/bit, 5nJ/bit/report and 10pJ/bit/m^2.The percentage of higher energy nodes (m) is 0.1 and the factor of energy gain (k) is 2. The size of the message packet that sensor nodes forward to aggregators as well as the size of message packet that aggregators forward to the sink is 4000 bits. The performance measures employed in this work are network lifetime, energy consumption and throughput.

Network Lifetime Analysis: This metric is measured as the time interval from the commencement of operation by the sensor nodes until the death of the last alive node. In Figure 1 (below), it is observed that the BED scheme shows a better performance because the first node dies after a considerably higher number of rounds (longer period of network stability) when compared to LEACH. As a result of this, the lifetime of the network is increased by adopting the BED scheme. A possible explanation for the performance of LEACH is that after the death of considerable number of sensor nodes, the aggregator selection process becomes unstable and consequently, lesser nodes become aggregators.

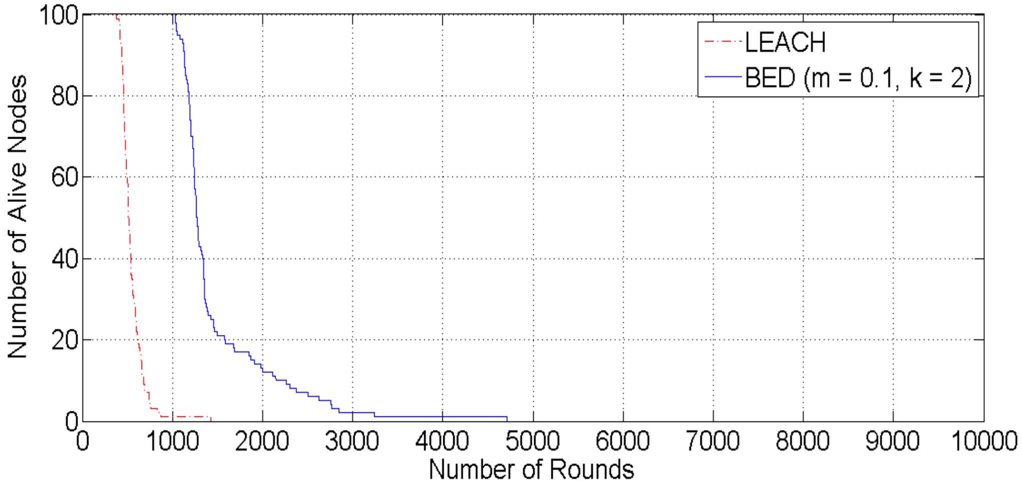

Fig. 1. Network Lifetime

Energy Consumption Analysis: This metric is measured as the total amount of energy consumed in the entire sensor network from the start of the network operation till the death of the last alive node. In Figure 2 (below), it is observed that the BED scheme exhibits better performance on an average when compared to LEACH. When there are comparatively lesser amount of nodes (< 30) in the network, LEACH consumes fewer amounts of energy than the BED scheme but when the network size grows denser and larger, it is observed that the BED scheme performs better than LEACH in terms of energy conservation. A possible explanation for this behavior is that the BED scheme allows the network to take full advantage of the additional energy of the higher energy nodes as the network size grows larger by favoring them to be elected more as aggregators compared to the lower energy nodes. As a result of this, the load is well balanced in the network and there is fair and slower consumption of the energy resources.

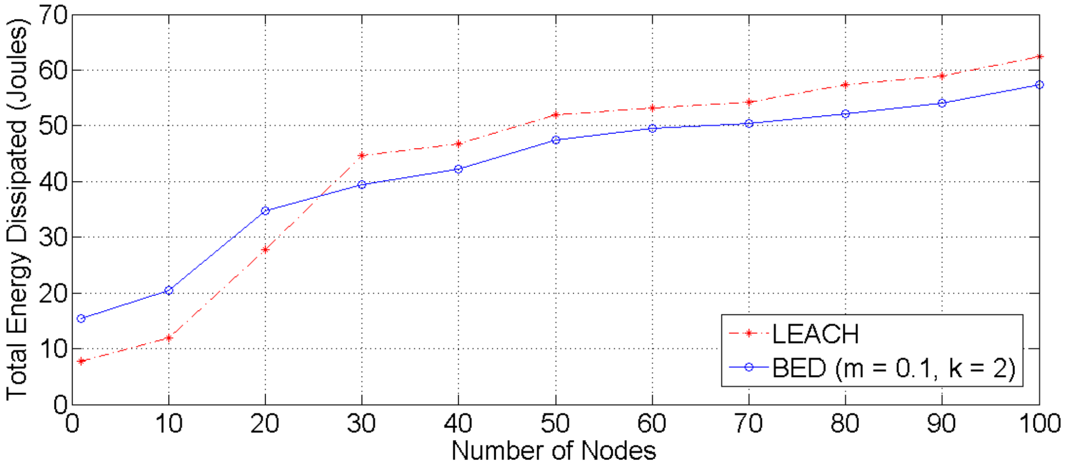

Fig. 2. Network Energy Consumption

Throughput Analysis: This metric is measured as the total packets sent over the network which is a summation of the total packets sent from nodes to their respective aggregators and the total packets sent from aggregators to sink. In Figure 3 (below), it is observed that the BED scheme displays a better performance than LEACH due to the longer period of network stability achieved in the BED scheme. As a result of this longer period of network stability, more packets were successfully transmitted to the sink. A possible explanation for the performance of the BED scheme is that the death process of the sensor nodes has been averaged. In other words, the higher energy nodes die naturally with approximately the same time like the lower energy nodes. This means that more energy resources can be used for longer period of time and these accounts for the longer period of network stability which enhanced the network throughput.

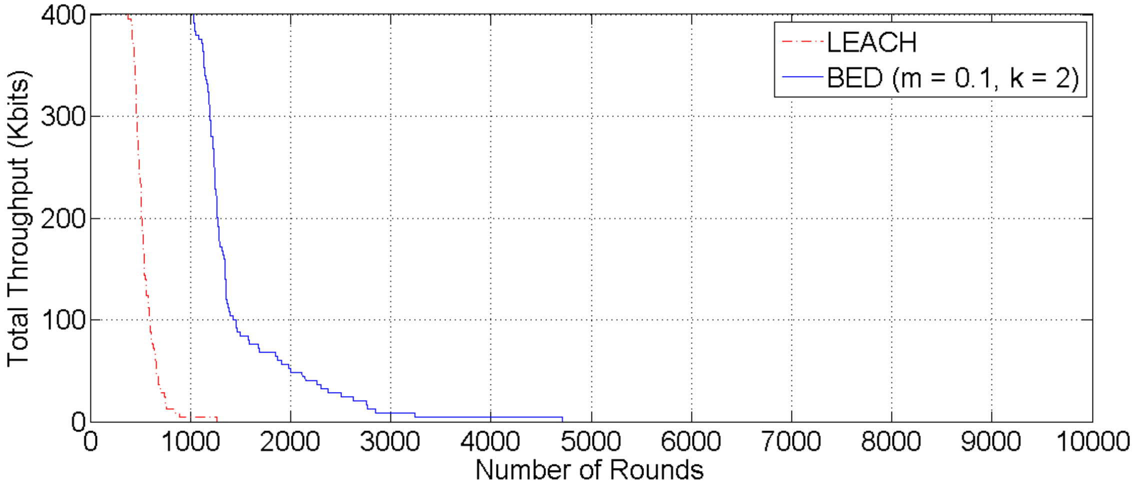

Fig. 3. Network Throughput

I. CONCLUSION AND FUTURE WORK

This Routing in sensor networks has attracted the attention of researchers and it has also posed interesting and important challenges. This paper presents BED (Biased Energy Distribution) scheme where a fraction of the entire sensor nodes is provided with higher energy than the remainder of the sensor nodes. High energy nodes are often chosen as aggregators which are given the responsibility of data aggregation and transmitting data to the sink. The pioneering routing protocol LEACH is not applicable for scalable sensor networks because aggregators communicate with the sink via single-hop transmission which is ineffective for large-scale sensor networks. Other routing algorithms address this challenging scalability issue by using multi-hop communication. In TEEN and APTEEN, only aggregators are used as relay nodes during the multi-hop transmission of data to the sink. On the other hand, in PEQ, CPEQ and ICE, cluster nodes, aggregators and free nodes are jointly employed for relaying data to sink. However, these protocols have shortcomings due to cluster configuration and network management overheads. In this research, we are currently developing an artificial intelligence based approach for determining and choosing the optimum value of *m* and *k*. We are also trying to investigate the effect the field area and node location have on the performance of the BED scheme.

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