An Energy Sorting Protocol (ESP) With Low Energy and Low Latency in Wireless Sensor Networks

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Summary
Data gathering is a critical operation in wireless sensor network applications, which necessitates energy efficiency techniques for increasing the lifetime of the network. Clustering is a similar effective technique that improves the energy efficiency and network lifetime in wireless sensor networks. This paper proposes an Energy Sorting Protocol (ESP) architecture in which clustering is used. The objective of ESP architecture in case of wireless micro-sensor networks is to accomplish low energy dissipation and latency without sacrificing application specific quality. In order to attain the objective, ESP employs (i) randomized, adaptive, self - configuring cluster formation (ii) localized control for data transfers and (iii) application - specific data processing, such as data aggregation or compression. In order to generate good clusters as the outcome, each node is permitted to make autonomous decisions by the cluster formation algorithm. Simulation results illustrate that, this algorithm also minimizes the energy and latency for cluster formation, in order to minimize overhead to the protocol.
Key words:
Sensor networks, Low latency, Energy sorting protocol, data processing, Cluster formation.

1. Introduction

The modern technical development that is competent of local processing and wireless communication has made exploitation of minute, economical, low-power, distributed devices a reality. These types of nodes are known as sensor nodes. In case of each sensor node, only a restricted amount of processing is killed. Nevertheless these nodes when synchronized with the information from a massive amount of other nodes depict the capability to gauge a provided physical environment in great detail. A collection of consequent sensor nodes can be employed to represent a sensor node coordinating to carry out a few definite actions. The sensor networks depend on dense deployment and co-ordination contrasting traditional networks to accomplish its responsibilities.

Earlier the sensor networks comprised of a few number of sensor nodes wired to a central processing station. But, these days the focus is more on wireless, distributed sensing nodes. However, what is the necessity of distributed, wireless sensing? [1]. In case the accurate location of a particular phenomenon is unfamiliar, closer placement to the phenomenon is permitted by distributed sensing than a particular sensor would permit. Additionally, the multiple sensor nodes are necessary in numerous cases to overcome ecological impediments like obstructions, line of sight constraints etc. In the majority cases of energy or communication, the observed environment does not possess an offered infrastructure. It is essential for sensor nodes to stay alive on minute, finite sources of energy and communicating through a wireless communication channel [2].

For the sensor networks the distributed processing capability is likely an additional necessity. This is essential as communication is a foremost consumer of energy. In case of the centralized system, there is a necessity for a number of sensors to communicate over long distances thereby causing more energy depletion. In order to reduce the total quantity of bits broadcasted, processing as much information as achievable in the neighborhood would be an excellent thought.

There are numerous applications which employ sensor networks, some of them are mentioned below. Environmental monitoring which deals with monitoring air soil and water, condition based maintenance. Habitat monitoring determines the plant and animal species population and behavior. Seismic detection, military surveillance, inventory tracking, smart spaces etc are worth mentioning. Certainly, due to the enveloping character of micro-sensors [3], the sensor networks have the potential to incredibly transform the complex physical system is understood and built.

The sensor constitutes a micro – controller, a radio transmitter, and an energy source. Sensing, communicating and computation are the three essential functions of a sensor network. Hardware, software and algorithms are the corresponding three basic components used in the implementation of the above mentioned basic functions.

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Each of the above function necessitates energy. Among all the functions, in case of communication, more energy is required. Therefore, a power conscious approach is necessary for the micro sensor network algorithms and protocols, which scales the energy usage in accordance with the given quality specification [4].

Thus, to increase the lifetime of the network vastly, proper energy efficient communication protocols should be designed. This paper proposes an Energy Sorting Protocol (ESP), in which a clustering architecture, for wireless micro sensor networks is used to facilitate the achievement of low energy dissipation and latency, in which application – specific quality is not sacrificed. The simulation results illustrate that, when compared to the general – purpose approaches, the ESP attains an order of magnitude increase in system lifetime. Additionally, the overall latency is reduced by an order of magnitude for a given quality.

This paper is organized as follows. Section 2 gives the detailed related work done. Section 3 presents the system model for our architecture. Section 4 gives the experimental results and section 5 concludes the paper.

2. Related Work

In case of MTE routing [5], the selection of routes from each node to the base station were performed such that each node's next–hop neighbor is the closest node that is in the direction of the base station. Each node requires 100 nJ to determine its next –hop neighbor. When a node dies, all of that node's upstream neighbors (i.e., all the nodes that send their data to this node) begin transmitting their data to the node's next – hop neighbor. Thus, whenever a node dies eliminating the need for computing the new routes.

Nodes adjust their transmit power to the minimum required to reach their next – hop neighbor. This reduces interference with other transmissions and reduces the node's energy dissipation. Communication with the next – hop neighbor occurs using a CSMA MAC protocol, and when collisions occur, the data are dropped. When a node receives data from one of its upstream neighbors, it forwards the data to its next – hop neighbor. This continues until the data reaches the base station.

LEACH [6] discuses an energy efficient algorithm which is the base for various algorithms developed after that. LEACH uses randomization technique to determine the cluster head. In the discussed algorithm, Sensors elect themselves to be local cluster – heads after every cycle or after certain time interval, with a certain probability. After that, these cluster heads broadcast their status to the other sensors in the network. Then each sensor node determines to which cluster it wants to belong by choosing the cluster – head that requires the minimum communication energy.

Once all the nodes are organized into clusters, each cluster – head creates a schedule for the nodes in its cluster, which allows the radio components of each node to be turned off at all times except during it's transmit time. Thus the energy dissipated in the individual sensors is minimized. Once the cluster – head has received all the data from the nodes in its cluster, the cluster – head node aggregates the data and then transmits the compressed data to the base station. Since the base station is far away from the area in which the sensors are deployed, the energy required for this transmission is more. However, since there are only a few cluster – heads, this only affects a small number of nodes. In the discussed algorithm, the node that acts as a cluster head can not become a cluster head before the completion of a predetermined time cycle and also the position of the sensors is not necessary to form a cluster.

In LEACH-C [7] algorithm, during the initial stage, each node has to send information about its current location and energy level to the base station. The base station runs an optimization algorithm to determine the clusters for that round. Thus, LEACH_C requires the position of each node at the beginning of each round. A global positioning system GPS is required for this purpose. The base station computes the average node energy. The nodes have energy below this average cannot become cluster heads for the current round. Using the remaining nodes as possible cluster heads, the base station runs an algorithm known as simulated annealing algorithm to determine the best nodes to be cluster heads for the next round and the associated clusters. Simulated annealing is an algorithm based on thermodynamics principles.

In LEACH-F [7], according to the discussed algorithm, the clusters are fixed and only the cluster heads are rotated. Here, a node should have to use a large amount of power to communicate with its cluster head when another cluster's cluster head is nearer. For initial cluster formation, the LEACH_F also uses the same annealing algorithm as in LEACH_C. The discussed algorithm is more energy efficient than LEACH_C. But the discussed algorithm can not be implemented in practical real time systems, because the interference of signals is more, the discussed algorithm does not allow new nodes to be added to the system, and does not adjust its behavior based on nodes – dying. Furthermore LEACH_F does not handle node mobility.

Ewa Hansen et al., [8] have presented simulation results from the experiments with a minimum separation distances between cluster heads and to determine how much the amount of energy consumption that can be lowered in the sensor network by separating the cluster heads, i.e., by distributing the cluster heads through the whole network.

They have presented a simple energy-efficient cluster formation algorithm for the wireless multihop sensor network AROS and shown that using a minimum separation distance between cluster heads improves energy efficiency, measured by the number of messages received at the base station. They also showed that it is better, up to 150% in our simulations, to use a minimum separation distance between cluster heads than not to use any minimum separation distance.

Ossama Younis and Sonia Fahmy [9] have presented a distributed, energy-efficient clustering approach for ad-hoc sensor networks. The presented approach is hybrid: cluster heads are probabilistically selected based on their residual energy, and nodes join clusters such that communication cost is minimized. The authors assumed the quasi-stationary networks where nodes are location-unaware and having equal significance. A key feature of the presented approach is that it exploits the availability of multiple transmission power levels at sensor nodes. Based on the discussed approach, the authors have introduced the HEED protocol, which terminates in a constant number of iterations, independent of network diameter. Simulation results demonstrate that HEED prolongs network lifetime, and the clusters it produces exhibit several appealing characteristics. HEED parameters, such as the minimum selection probability and network operation interval, can be easily tuned to optimize resource usage according to the network density and application requirements. HEED achieves a connected multi-hop inter-cluster network when a specified density model and a specified relation between cluster range and transmission range hold.

S. Lindsey and C. S. Raghavendra [10] have described PEGASIS, a greedy chain protocol that is near optimal for a data-gathering problem in sensor networks. 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 receives among all nodes, and using only one transmission to the BS per round. Nodes take turns to transmit the fused data to the BS to balance the energy depletion in the network and preserves robustness of the sensor web as nodes die at random locations. Distributing the energy load among the nodes increases the lifetime and quality of the network. The simulations by the author show that PEGASIS performs better than LEACH by about 100 to 300% when 1%, 20%, 50%, and 100% of nodes die for different network sizes and topologies. PEGASIS shows an even further improvement as the size of the network increases.

Mao Ye et al., [11] have presented a novel distributed, energy efficient and load balanced clustering scheme applied for periodical data gathering. EECS produces a uniform distribution of cluster heads across the network through localized communication with little overhead. What's more, a novel approach has been discussed that distributes the energy consumption among the sensors in the cluster formation phase. Simulation results show that EECS prolongs the network lifetime as much as 135% of LEACH and the total energy is efficiently consumed.

Hang Su and Xi Zhang [12] have extended the existing analytical model to derive the optimized parameter – the number of clusters – for BCCA and show its correctness by simulations. The analytical analyses by the authors reveal the insight that the original analytical model underestimates the optimal number of clusters and thus needs to be modified. The simulation results verified the analyses and show that the modified model they discussed was more accurate in deriving the optimal number of clusters to maximize the lifetime of wireless sensor networks. Based on the above modified model, they also discussed and analyzed the clustering reconfiguration schemes: T-Driven and ET-Driven to improve the network lifetime of the sensor networks. The simulation results show that the discussed ET-Driven can significantly prolong the wireless sensor network lifetime as compared to that using the T-Driven and LEACH-CHRS scheme.

M. J. Handy, M. Haase and D. Timmermann [13] have discussed two modifications of LEACH’s cluster-head selection algorithm. With these modifications a 30 % increase of lifetime of micro sensor networks can be accomplished. Furthermore, an important quality of a LEACH network is sustained despite the modifications: For the deterministic selection of cluster-heads only local and no global information is necessary. The nodes themselves determine whether they become cluster-heads. A communication with the base station or an arbiter-node is not necessary. Additionally, the metrics FNA, HNA and LND which describe the lifetime of a micro sensor network have been presented.

3. The Energy Sorting Protocol (ESP) Architecture

We have designed and implemented Energy Sorting Protocol (ESP), a protocol architecture for wireless micro sensor networks that achieves low energy dissipation and latency without sacrificing application – specific quality. Since data are correlated and the end – user only requires a high – level description of the events occurring in the environment the nodes are sensing, the nodes can collaborate locally to reduce the data that need to be transmitted to the end – user. Correlation is strongest among data signals from nodes that are close to each other, suggesting the use of a clustering infrastructure that allows nodes that are close to share data. Therefore ESP uses a clustering architecture, where the nodes in the cluster send their data to a local cluster – head. This node is responsible for receiving all the data from nodes within the cluster and aggregating this data into a smaller set of information that describes the events the nodes are sensing. Thus the cluster – head node takes a number of data signals and reduces the *actual* data (total number of bits), while maintaining the *effective* data (information content). The cluster – head node must then send the aggregate data set to the end – user [6].

Since there may be no fixed infrastructure with a high – energy node that can act as a cluster – head, one of the sensor nodes must take on this role. If this position was fixed, the cluster – head would quickly use up its limited energy and die, ending the communication ability of the rest of the nodes in the cluster as well. Therefore ESP includes rotation of this cluster – head position among all the nodes in the network to evenly distribute the energy load. In order to rotate cluster – head nodes and associated clusters, the cluster formation algorithm must ensure minimum overhead, in terms of time and energy. Once clusters have been formed, the nodes must communicate their data to the cluster – head node in an energy efficient manner.

ESP therefore uses the following techniques to exploit the application – specific functionality of a sensor network and achieve energy and latency efficiency

(i) randomized, adaptive, self - configuring cluster formation,
(ii) localized control for data transfers, and
(iii) Application - specific data processing, such as data aggregation or compression.

The cluster formation algorithm allows each node to make autonomous decisions that result in good clusters being formed. This algorithm also minimizes the energy and latency for cluster formation, in order to minimize overhead to the protocol. Finally, local data processing achieves a large energy reduction by performing computation on the correlated data to greatly reduce the amount of data that must be transmitted long distances.

3.1 ESP Architecture

Currently, there is a great deal of research in the area of low – energy radios. Different assumptions about the radio characteristics, including energy dissipation in the transmit and receive modes, will change the advantages of different protocols. In our work, we assume a simple model where the radio dissipates E_{elec} = 50 nJ / bit to run the transmitter or receiver circuitry and ϵ_{amp} = 100 pJ / bit / m2 for the transmit amplifier to achieve an acceptable E_b / N_o. These parameters are slightly better than the current state of the art in radio design. We also assume an r^2 energy loss due to channel transmission. Thus, to transmit a k-bit message a distance d using our radio model, the radio expends:

$$E_{Tx}(k,d) = E_{Tx} - elec(k) + E_{Tx-amp}(k,d)$$

$$E_{Tx}(k,d) = E_{elec} * k + \epsilon_{amp} * k * d^2 \quad (1)$$

and to receive this message, the radio expends:

$$E_{Rx}(k,d) = E_{Rx-elec}(k)$$

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

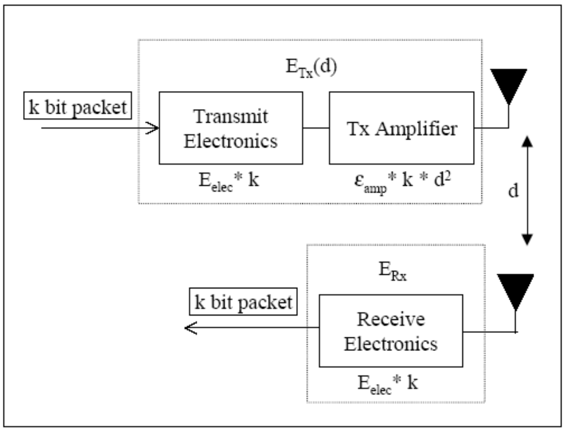

Fig. 1 First order radio model

Table 1 Radio characteristics

Operation	Energy Dissipated
Transmitter Electronics ($E_{Tx-elec}$) Receiver Electronics ($E_{Rx-elec}$) ($E_{Tx-elec} = E_{Rc-elec} = E_{elec}$)	50 nJ / bit
Transmit Amplifier (ϵ_{amp})	100 pJ / bit / m^2

For these parameter values, receiving a message is not a low cost operation; the protocols should thus try to minimize not only the transmit distances but also the number of transmit and receive operations for each message.

We make the assumption that the radio channel is symmetric such that the energy required to transmit a message from node A to node B is the same as the energy required to transmit a message from node B to node A for a given Signal to Noise Ratio. For our experiments, we also assume that all sensors are sensing the environment at a fixed rate and thus always have data to send to the end-user. For future versions of our protocol, we will implement an "event – driven" simulation, where sensors only transmit data if some event occurs in the environment.

3.2 Different Cycles of ESP

3.2.1 First Cycle

The data to be sent to the base station by the nodes are initially sent to the cluster heads and then the cluster head will send the consolidated data to the base station. So the data is first sent to the corresponding cluster heads. For sending the data, the nodes require certain energy which is calculated by applying the radio model. So after sending the data, the energy of the nodes are reduced from the initial energies. Then we calculated the energy required to consolidate the data received from the nodes and energy required to send the consolidated data to the base station by the cluster heads. Those energies are reduced from their initial energies.

3.2.2 Consecutive cycles

All the energies of individual nodes are compared with each other. The top 5 nodes which are having higher energies compared to others are elected as new cluster heads for the consecutive cycles. Now all the steps of cycle are repeated until all the energies of nodes are dried up which is known as death of nodes. The nodes which are alive after every cycle are calculated. Finally the graph between the number of nodes alive versus number of cycles is plotted.

4. Simulation results

4.1 Simulation Parameters

We evaluate our ESP scheme through NS2 simulation. We considered a 50 node random network deployed in an area of 100 X 100 m. Initially the nodes are placed randomly in the specified area. The base station is assumed to be situated 100 meters away from the above specified area. We also assume that 5% of nodes are considered as cluster heads for the entire cycles. Obviously, the first set of cluster heads are taken randomly. The initial energy of all the nodes assumed as 0.5 joules. The cluster heads which are closer to every node will act as a cluster head for those nodes for the first cycle. The nodes and the cluster head nearer to those nodes will form a group. Thus we formed 5 groups since we have five cluster heads.

In our simulation, the channel capacity of mobile hosts is set to the same value: 2 Mbps. We use the distributed coordination function (DCF) of IEEE 802.11 for wireless LANs as the MAC layer protocol. The simulated traffic is FTP with TCP source and sink. All experimental results presented in this section are averages of five runs on different randomly chosen scenarios. The following table summarizes the simulation parameters used.

Table 2: Simulation Parameters

No. of Nodes	50
Area Size	100 X 100
Mac	802.11
Simulation Time	50 sec
Traffic Source	FTP
Packet Size	512
Transmit Power	0.360 w
Receiving Power	0.395 w
Idle Power	0.335 w
Initial Enegy	0.5 J
Transmission Range	75m

4.2 Simulation Results

We compare the performance of our proposed ESP architecture with LEACH [6]. We evaluate mainly the performance according to the following metrics:

Average Energy Consumption: The average energy consumed by the nodes in receiving and sending the packets are measured

Life time of the network: The total number of nodes which are alive at end of all cycles of the algorithm.

Average Throughput: The average number of packets received at the sink.

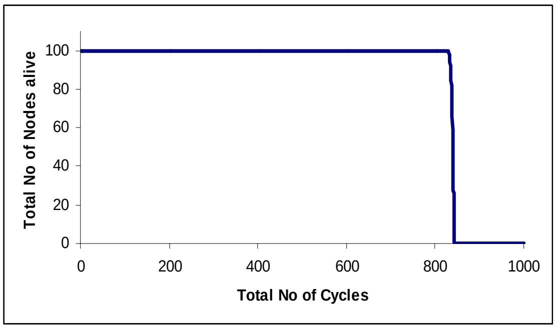

Fig. 2 The life time of the ESP network when initial energies of all nodes are 0.25 J.

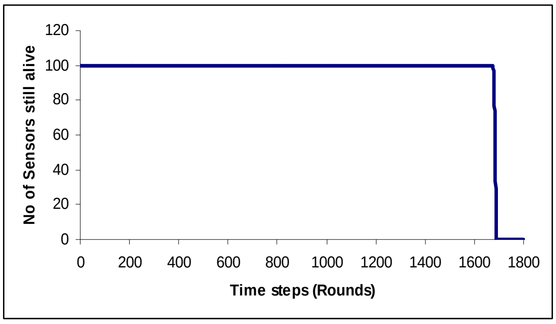

Fig. 3 The life time of the ESP network when the initial energies of all nodes are 0.5 J.

Fig. 2 and 3 shows the life time of the ESP network when the initial energies of all nodes are 0.25 J and 0.5 J respectively.

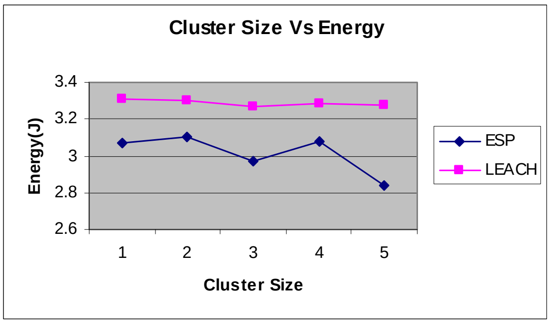

Fig 4 Cluster Size Vs Energy

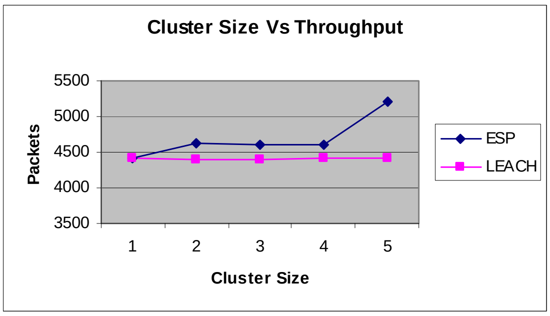

Fig. 5 Cluster Size Vs Throughput

Fig. 4 and 5 shows the average energy consumption and throughput of ESP and LEACH, respectively, when the cluster size is increased.. From the figures, we can see that ESP has less energy consumption and more throughput, when compared to LEACH.

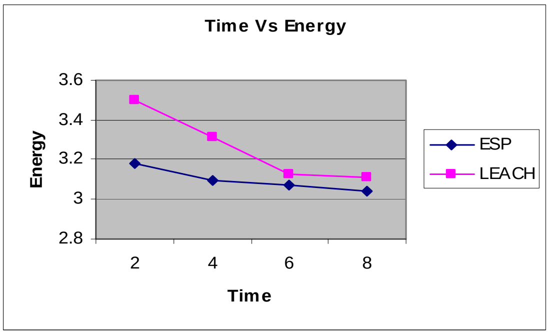

Fig. 6 Time Vs Energy

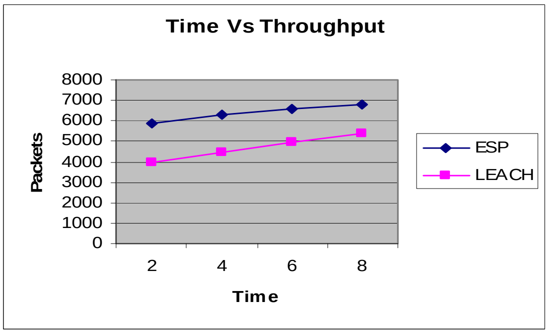

Fig. 7 Time Vs Throughput

Fig. 6 and 7 shows the average energy consumption and throughput of ESP and LEACH, respectively, at various time intervals of the simulation. From the figures, we can see that ESP has less energy consumption and more throughputs, when compared to LEACH.

5. Conclusion and Future Work

A power conscious approach is necessary for the micro sensor network algorithms and protocols, which scales the energy usage in accordance with the given quality specification. Consequently, it is essential to design protocols and algorithms for wireless networks to be bandwidth, and energy – efficient. Thus, to increase the lifetime of the network vastly, proper energy efficient communication protocols should be designed. This paper proposes an Energy Sorting Protocol (ESP) in which employs a clustering architecture for wireless micro-sensor networks in which low energy dissipation and latency without sacrificing application specific quality is accomplished. The simulation results illustrate that, the ESP attains an order of magnitude increase in system lifetime.

The area of protocols for wireless micro sensor networks provides space for more work to be done. This research

discusses the protocols for scenarios limited to sensors having correlated data. Nonetheless there are applications of micro sensor networks devoid of the above limitation.
For instance, sensor networks for medical monitoring applications may constitute dissimilar sensors located on and / or in the body which monitor vital signs. Though these networks will not be as large – scale as the ones we discussed, their requirements are similar to the sensor networks we discussed – long system lifetime, low – latency data transfers, and high quality data. The prime focus of these networks is to maximizing quality above all parameters, which mainly forbids loss of information. In order to support the unique considerations of these networks, protocol architectures need to be developed.

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