Distributed Energy Aware Routing Protocol for Wireless Sensor Network

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ABSTRACT
Wireless Sensor Networks consist of a large population of sensor nodes capable of computation, communication and sensing. Limited energy resource is the inherent limitation of Wireless Sensor Network, Most routing algorithms for Sensor Network focus on energy efficient paths, Due to this, power in the sensor, along the energy efficient paths gets depleted very quickly, and therefore Sensor Networks becomes incapable of monitoring events from certain parts of the targeted area. Ideally, routing algorithm should consider not only energy efficient (shortest) path but also available energy at every Sensor node along the path, thereby delaying the non- functioning of sensors due to early power depletion. In this paper, we are introducing two new metric like thresholds, energy cost to find energy critical sensor node and energy efficient path respectively. These two metric gives rise to the design of Distributed Energy Aware Routing Protocol (DEARP) for Wireless Sensor Networks. DEARP is designed to generate routing paths in a decentralized manner, while considering the energy efficiency, and available energy in each sensor node to avoid early power depletion. Experimental result shows the effectiveness of proposed algorithm in terms of network lifetime, energy consumption and Quality of Service (QoS) parameters. Comparative analysis of DEARP with the widely used AODV shows that energy cost along with available energy in each node should be considered to extend lifetime of Sensor Network.

Keywords
Wireless Sensor Network, energy efficient routing algorithm, Distributed Energy Aware Routing Protocol

1. INTRODUCTION
A wireless sensor network (WSN) consists of a large number of sensor nodes that may be randomly and densely deployed. Sensor nodes are small electronic components capable of sensing different types of information from the environment, such as temperature, light, humidity, radiation, the presence of biological organisms, geological features, seismic vibrations, specific types of computer data and many more. Recent advancements in micro-electro mechanical system (MEMS) technology have made it possible to make these components small, powerful, and energy efficient. These sensor nodes can now be manufactured cost-effectively in quantity for specialized telecommunications applications. Very small in size, the sensor nodes are capable of gathering, processing, and communicating information to other nodes and to the outside world. Based on the information handling capabilities and compact size of the sensor nodes, sensor networks are often referred to as "smart dust."

Sensor Networks are highly distributed networks of small, lightweight nodes termed motes, deployed in large numbers to monitor the environment or a system by the measurement of physical parameters. A sensor node is the basic electronic building block of a WSN and is a self contained modular low-cost electronic system that consists of three major functional units viz. sensing, computation and communication, packed in a small unit, about 1 inch in diameter. The sensing element monitors a variety of ambient conditions, characteristics of objects and their motion. The computation unit can include data analysis such as summation, aggregation of related data. The communication unit consists of RF transmission and reception between different nodes within the vicinity of the transmission range. Figure 1 shows the Radio Energy consumption model for WSN.

Many WSN applications require thousands of sensor nodes that are deployed in remote locations, where human intervention is difficult or sometimes almost impossible, this makes battery replacement impractical. Since the nodes are battery operated, nodes may get power deflated if not handled properly. Traditional routing algorithms are not designed as per the requirement of WSN. Therefore, energy efficient routing paradigms are an area of active research. WSN has certain challenges of designing routing protocols; the reasons of it are as stated below.

- Sensor nodes are randomly deployed
- Sensor networks are without any infrastructure.
- Being a battery operated device, available energy can be the bottleneck in the operation of sensor nodes.
- Sensors usually rely on their battery for power, which in many cases cannot be recharged or replaced.
- Sensor networks are highly dynamic therefore it should be capable to adapt topological changes, due to failure of nodes, or powering up of new node.

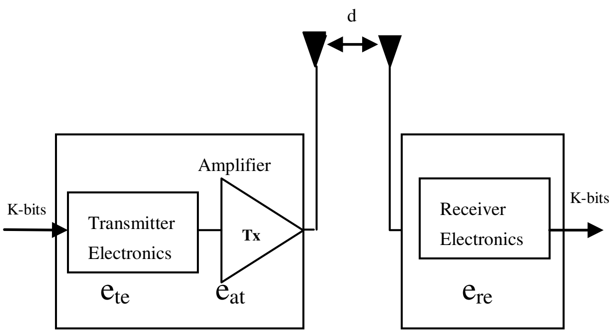

Figure 1. Radio Energy Consumption Model

Contribution: In this paper, we present a routing protocol which achieves considerable energy saving thus increasing the throughput and network lifetime. Working of proposed routing protocol is similar in nature with Ad-Hoc on Demand Distance Vector Routing Protocol (AODV). In proposed protocol, energy critical nodes do not take part in routing, preserving themselves only for sensing purpose and thus delaying the energy depletion and in turn extending the network lifetime.

Organization: The paper is organized as follows: Section II presents the related work while Section III describes the Network Architecture. Section IV gives the proposed algorithm. Experimental set-up is given in section V. Results are given in section VI, whereas section VII presents the conclusions.

2. RELATED WORK

This section gives the brief information of research in routing protocols for WSN. Ian et al. [01] present a survey of sensor networks. In [02], the authors have said that the Traditional sensor network routing algorithms are not optimized for energy conservation. Therefore, energy efficient routing paradigms are an area of active research. Changsoo et al. [03] have devised Distributed Energy Adaptive Routing (DEAR) algorithm to balance the data traffic of sensor networks in a distributed manner and consequently prolong the lifetime of the network. Jussi et. Al. [04] have given a detailed energy survey of the physical, data link, and network layer through analytical techniques and said that regular coordinated sleeping extends the life time of the sensor nodes, but systems can only benefit from sleeping in terms of transmitted packets if the data arrival rate to the system is low. W. R. Heinzelman et. al. [05] have proposed LEACH (Low Energy Adaptive Clustering Hierarchy), a clustering based protocol that utilizes random selection of cluster head so as to evenly distribute the energy load among the working sensors. Itanagonwiwat et al. [06] have presented Directed Diffusion Protocol [DDP]. In this protocol, a sink requests data by sending interests for named data. Data matching the interest is then drawn toward that node. Intermediate nodes can cache or transform data, and may direct interests based on previously cached data. In [07], Krishnamachari et al. have suggested the concept of data aggregation. The main idea is to aggregate the data originating from different sources so as to eliminate redundancy, and thereby minimizing the number of transmissions, and thus saving energy. Ganesan et al. [08] present Multi-path Routing algorithm. The focus of this algorithm is to extend the life of the network by conserving energy. The said algorithm conserves energy by prudently avoiding the costly flooding phase of Directed Diffusion. A family of protocols called Sensor Protocols for Information via Negotiation (SPIN) is proposed in [09]. SPIN is a source initiated directed diffusion scheme, developed at the Massachusetts Institute of Technology (MIT). SPIN uses negotiation and resource adaptation to address the deficiencies of flooding. Lindsey et al. [10] have proposed Power-Efficient Gathering for Sensor Information Systems (PEGASIS), a data gathering protocol based on the assumption that all sensor nodes know the location of every other node in the network. In [11], Yan et. al., propose a new ant colony routing protocol. This uses the tracking range of mobile nodes to split the path between source node and destination node into two paths. In [12], Daisuke et. al, have proposed two anonymous routing algorithms, viz. randomized routing algorithm, and probabilistic penalty based routing algorithm. Objective is to differentiate routing paths to the same destination enhancing anonymity of the network traffic. N. Chilamkurti et. al [13], have exploit cross-layer optimizations technique that extends the DSR to improve its routing energy efficiency by minimizing the frequency of reforming routes.

3. NETWORK ARCHITECTURE

WSN's are large number of sensor nodes, highly distributed, and self-organized systems. They have strong limitations in terms of processing, memory, communications and energy capabilities. Sensor nodes collect measurements of interest over given space, making them available to external world through a special node called sink or base station, either via single hop or multihop communication. Figure 2 shows the working of linear Sensor Network. Radio resource and energy management is an important aspect of any wireless network. Following performance metrics are used for study of energy efficiency of the WSN:

- Delivery Ratio: Number of packets received at sink divided by the number of packets send by the source.
- Network lifetime: It is defined as the time elapsed until the first node (or the last node) in the network depletes its energy (dies).
- Throughput: It is defined as the total number of packets received at the sink divided by the simulation time.

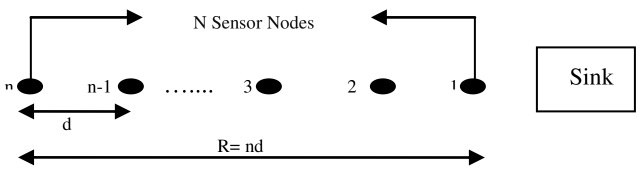

Figure 2. Working Of Linear Sensor Network

4. PROPOSED ALGORITHM

The proposed routing algorithm uses two new metric called, thresholds, and energy cost to consider available energy in every sensor node, and to check energy efficiency respectively. These two metric gives rise to the design of DEARP for Wireless Sensor Networks. DEARP is designed to generate routing paths in a decentralized manner, while considering the energy efficiency, and available energy in each sensor node to avoid early power depletion. Threshold value is taken as 80% of average energy value of the network, therefore in every round of route finding process, threshold values are required to be calculated. Energy cost depends upon the number of hops between source and destination, as the transmission power is directly proportional to the square of the distance between source and destination node. By using these two metric, network life time of WSN is prolonged. Energy cost for data transmission from node i to j is:

$$ECij = \text{Required energy from node i to j} \quad (01)$$

The Total Energy Cost (TECik) of a path k at sensor node i is the sum of energy costs along the path

$$TECik = \sum_{ij \in k} ECij \quad (02)$$

Where i is the destination node, K is the path from source node.
A path K will be selected as routing path if

TECiK=Min TEC A

Where ik € A, and A is the set of all possible routing paths.

Threshold=0.8*Average Energy of the Network (03)

Whenever a sensor node has to forward root request (RREQ) packet to the next node, the node checks its available balanced energy, if it is more than the threshold value then only it take part in routing by broadcasting the RREQ packet otherwise, it simply drops the RREQ packet, denying to take part in routing, energy critical nodes do not take part in routing, and preserve them self only for sensing phenomena and hence delaying the non-functioning of sensors due to early power depletion and extending the network lifetime.

Example

In Figure 3, node n1 has data to send to base station. Node n1 has three alternative routes to the base station such as root 1: n1-n2-n3-base station, root 2: n1-n4-base station, root 3: n1-n5-n6-n7-base station. Source and Base Station nodes are excluded while calculating average energy of the network because source node has to participate in routing irrespective of available energy whereas base station assumed to be without any energy constraints. In route 2, node 4 will not take part in routing as it has available balanced energy (E4-10) is less than threshold, therefore this path is not seen by the destination (Base Station) and hence will not be considered for routing. Route 1 has 3 hops where as route 3 has 4 hops to reach to base station. Therefore route 1 will be selected for data transmission and will be continued till the energy level of all the nodes along this path is greater than threshold.

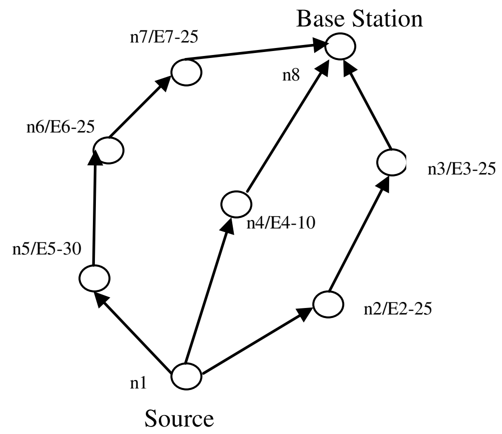

Figure 3. Example Scenario: node n1has data to send to Base Station. (a) Average energy of the network excluding source and base station is 23.33.(b) Threshold value is 18.66 (c) node n4 will not take part in routing as its energy level < threshold.

Route request: Whenever a node has data to send and route is not available for destination node, a route request Packet (RREQ) with following fields is flooded through the network.

Source Address	Request Id	Source Sequence Number	Destination Address	Destination Sequence Number	Hop Count

The request ID is incremented each time the source node sends a new RREQ, so the pair (source address, request ID) identifies a RREQ uniquely. On receiving a RREQ message each node checks the source address and the request ID. If the node has already received a RREQ with the same pair of parameters the new RREQ packet will be discarded else If the processing node is the destination node, then the reply is send back through root reply (RREP) packet, else if the processing node is the intermediate node, then the RREQ packet is forwarded if the available balanced energy of that node is greater than the threshold value else the RREQ packet is discarded, denying to take part in routing. This is where our proposed routing algorithm differs from traditional AODV[14].

If the node has no route entry for the destination, or it has one but this is no more an up-to-date route, the RREQ will be rebroadcasted with incremented hop count if the node has a route with a sequence number greater than or equal to that of RREQ, a RREP message will be generated and sent back to the source. The number of RREQ messages that a node can send per second is limited.

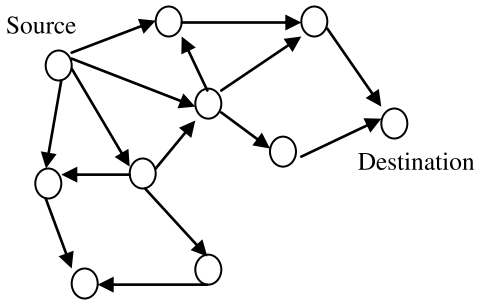

Figure 4. Route Request Process

There is an optimization of AODV using an expanding ring (ESR) technique when flooding RREQ messages. Every RREQ carries a time to live (TTL) value that specifies the number of times this message should be re-broadcasted. This value is set to a predefined value at the first transmission and increased at retransmissions. Retransmissions occur if no replies are received. Historically such flooding used a TTL large enough - larger than the diameter of the network - to reach all nodes in the network, and so to guarantee successful route discovery in only one round of flooding. However, this low delay time approach causes high overhead and unnecessary broadcast messages.

Route reply: If a node is the destination, or has a valid route to the destination, it uncast RREP back to the source. This message has the following format:

Source Address	Destination Address	Destination Sequence Number	Hop Count	Life TIme

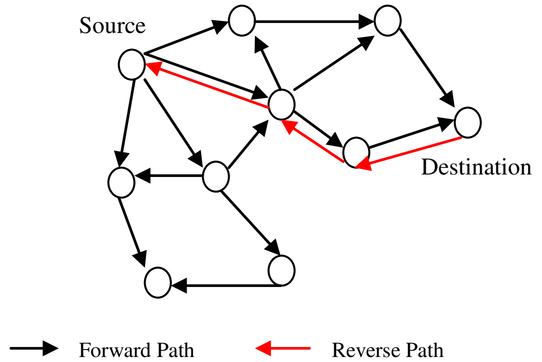

Figure 5. Route Reply Process

Reverse path setup: While transmitting RREQ messages through the network each node notes the reverse path to the source. When the destination node is found the RREP message will travel along this path, so no more broadcasts are needed. For this purpose, the node on receiving RREQ packet from a neighbor records the address of this neighbor.

Forward path setup: Whenever a broadcast RREQ packet arrives at a node having a route to the destination, the reverse path is used for sending a RREP message. While transmitting this RREP message the forward path is created. As and when the forward path is built, data transmission can be started. Data packets waiting to be transmitted are buffered locally and transmitted in a FIFO-queue when a route is set up. After a RREP was forwarded by a node, it can receive another RREP. This new RREP will be either discarded or forwarded, depending on its destination sequence number:

If the new RREP has a greater destination sequence number, then the route should be updated, and RREP is forwarded. If the destination sequence numbers in old and new RREPs are the same, but the new RREP has a smaller hop count, this new RREP should be preferred and forwarded, Otherwise all later arriving RREPs will be discarded

5. EXPERIMENTAL SETUP

The Qualnet 4.5[15] Network Simulator is used for the analysis. MAC, Physical layer protocol used for experimentation are IEEE 802.11. In the scenario UDP (User Datagram Protocol) connection is used and over it data traffic of Constant bit rate (CBR) is applied between source and destination. Grid of 16 nodes as shown in figure 6 is prepared with 200M distance between each node. Initial energy of nodes 6, 11, and others remaining nodes is 500, 300, 2500 respectively. A CBR is set-up between node 1 and 16. Table 1 shows the simulations parameters used during simulation.

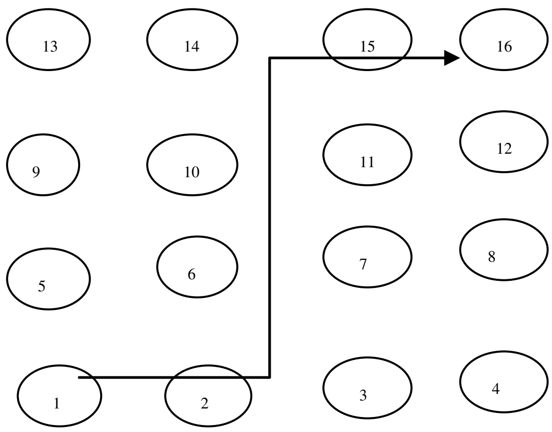

Figure 6. 4*4 Grid used for Experimentation

Table 1. Simulation Parameters

Parameter	Parameter value
No. of Nodes and Area	16 and 1500m*1500m
Simulation time	4Minute
Channel frequency	2.4GHz
Transmission range	250 meter
TX-Power	0dBm
Path Loss Model	Two Ray Model
Phy and MAC Model	802.11
Energy Model	MICAZ Mote
Battery Model	Simple Linear,1200 mAhr,
Packets Per Second (PPS)	0.1,1,2,5,10
Payload Size	512 bytes

6. RESULTS AND DISCUSSION

In this section, we provide experimental results to validate the effectiveness of DEARP. We have implemented the proposed algorithm in C programming Language and used the environment of Qualnet 4.5 to simulate it; generated results are compared with traditional AODV.

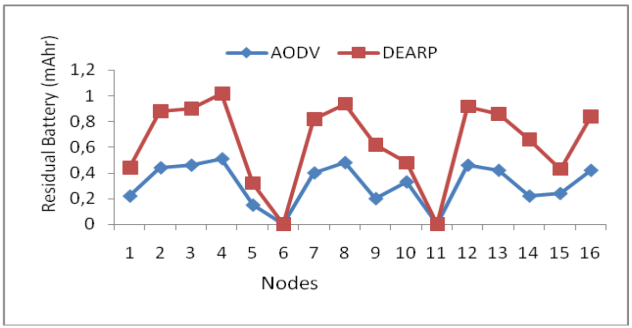

Figure 7. Residual Energy of nodes using AODV and DEARP

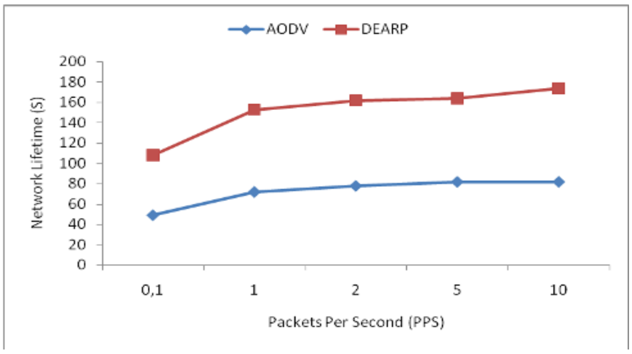

Figure 8. Comparative analysis of Network Lifetime using AODV and DEARP

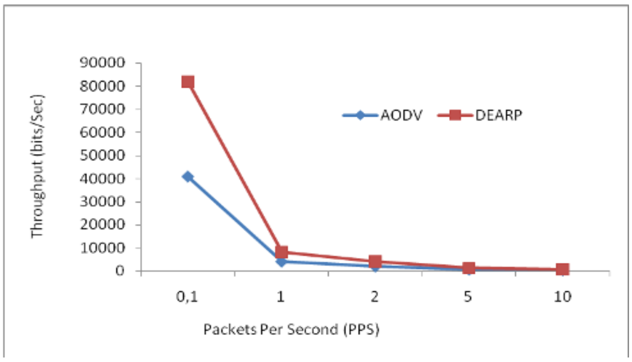

Figure 9. Throughput obtained using AODV and DEAR

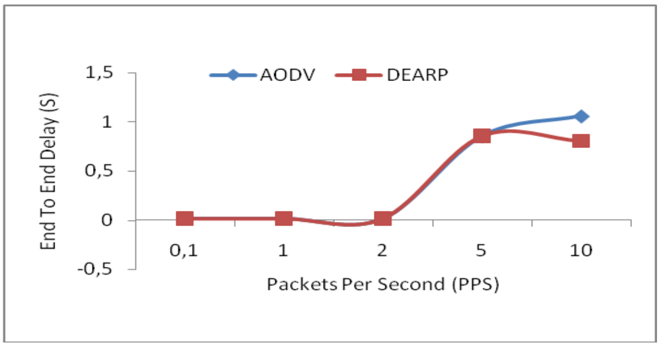

Figure 10. Average End To End Delay

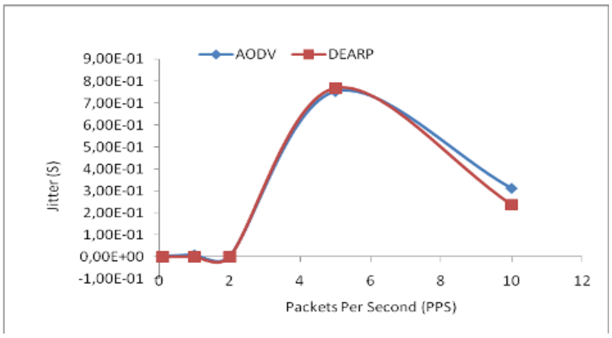

Figure 11. Average Jitter

Figure 7 shows that the residual energy of nodes after the simulation using AODV and DEARP. Path selected by AODV during simulation is through the nodes 1-6-11-16 and that of DEARP is 1-5-10-15-16 (Figure 6). Nodes 1, 16 are source, Destination nodes respectively. Path selected by AODV is the shortest one but with full of energy critical nodes (6,11) where as path selected by DEARP is without any energy critical nodes. Therefore number of path breaks in AODV is more than DEARP. This leads to more energy consumption for path set-up process. Figure 8 shows Comparative analysis of Network Lifetime using AODV and DEARP. Experiment is repeated for different data rates (Packets per Second). Result shows that the network lifetime is extended for DEARP over AODV for all cases, the average lifetime of network using DEARP for given scenario is improved by some considerable factor as well. Figure 9 shows that the total number of packet received at destination is more and hence the throughput for DEARP is higher as compared to AODV. The amount of energy required for path set-up is proportional to the no of path breaks. AODV has more path breaks than DEARP, therefore considerable amount of energy is consumed for path set-up process. DEARP selects the path by avoiding energy critical nodes. Therefore we could say that this difference in throughput is because of route selection strategy used in DEARP. AODV does not care about balanced available energy at nodes during path selection, hence the routing path selected by AODV was shortest but with full of energy critical nodes. Some of the energy critical nodes such as 6,11 (figure 7) got exhausted over a period of time and a path break occurred. This resulted in new path finding process that consumes some considerable amount of battery power.

Ultimately this entire process leads to reduction in throughput and reduced network lifetime. On the other hand, DEARP has selected the energy efficient path by avoiding the energy critical nodes there (6,11) hence no path break during data transmission. DEARP preserves energy critical nodes and uses it only for sensing purpose and thereby extending the network lifetime. Figure 10, 11 shows end to end delay and jitter observed for the given scenario using DEARP and AODV.

7. CONCLUSION

Sensor Network will be able to balance the energy across the network as well as able to select energy efficient paths by preserving energy critical nodes to prolong their lifetimes. Most of the energy aware routing algorithms are concerned about energy efficiency only whereas in this paper, we presents two metrics such as energy cost and threshold to select energy efficient path and preserve energy critical nodes respectively. Using these two metrics, we have designed and implemented DEARP.

The designed algorithm demonstrates its superiority over traditional AODV with a network lifetime, available balanced energy and throughput that are generally accepted for evaluation of routing algorithm.

Future Work: During data delivery process, amount of energy required for path set-up process is proportional to the number of path breaks which in turn is related to the robustness of the path selected. This indicates that the robustness of the path selected for data transmission might play important role to improve the network lifetime, and throughput. Hence our future work will be towards the robustness of the path selected to improve network lifetime.

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