Energy Utilization of HTAP under Specific Node Placements in Wireless Sensor Networks

Charalambo Sergiou and Vasos Vassiliou
Networks Research Laboratory (NetRL)
Department of Computer Science
University of Cyprus
Nicosia, Cyprus
email: {sergiou, vasov} @cs.ucy.ac.cy

Abstract—Energy utilization is a challenging task that is being encountered in low-powered Wireless Sensor Networks (WSNs) when designing an algorithm, protocol or hardware. Congestion is a factor that can affect a network’s lifetime (and energy utilization), since it usually leads to packet drops or collisions in the medium followed by possible retransmissions. Forwarding data packets through alternative paths is a way to counter congestion in WSNs. Proper node placement is essential to ensure good sensing coverage and communication connectivity. Node placement could also be affected by the need to create multiple routes to the sink; therefore, it can be proven vital for the improvement of energy utilization performance of this type of congestion control algorithms. In this paper we evaluate the energy utilization performance of HTAP (Hierarchical Tree Alternative Path) a congestion control and avoidance algorithm whose operation is based on a multipath routing scheme. HTAP energy utilization is evaluated under specific node placements and in correlation with a comparable routing scheme (Directed Diffusion). Through simulations, conclusions are extracted, suggesting node placements that assist in uniform and efficient energy utilization in WSNs.

I. INTRODUCTION

Wireless Sensor Networks (WSNs) consist of spatially distributed autonomous sensor-enabled devices that cooperatively monitor physical or environmental conditions such as temperature, sound, vibration, pressure, motion or pollutants at different and often remote locations [1]. Early research studies in WSNs targeted military applications, especially for battlefield monitoring. In the last few years, due to the progress of low power units and improvements in radio technologies, wireless sensor networks technologies have gained momentum. WSNs are now being deployed in civilian areas and being used for habitat observation [2][3], health monitoring[4], object tracking [5][6] etc. In addition, there is an emergence of mission-critical applications in which performance control is essential [7].

Node Placement and Congestion Control are two important factors that affect the energy utilization performance of a WSN in terms of increased lifetime and reliable data transmission.

In this paper we evaluate the energy utilization performance of a Congestion Control and Avoidance algorithm, HTAP [8], under specific node placements and provide results in correlation with Directed Diffusion [9] a "classical" and comparable multipath routing protocol. HTAP is a completely dynamic algorithm that bases its alternative path selection on the specific node’s congestion situation while Directed Diffusion is a protocol that reinforces high data rate paths, while it prunes data rate inefficient paths.

II. RELATED WORK

Several node placements have been proposed in literature concerning WSNs.

Younis et al [10] present a survey for strategies and techniques for node placements in WSNs and provide a categorization of the placement strategies into static and dynamic depending on whether the optimization is performed at the time of deployment or while the network is operational.

Toumpis et al [11] provide an optimal deployment of large wireless sensor networks so as to minimize the number of nodes that is needed in order to transmit data from multiple sources to multiple sinks.

In [12] authors evaluate the tolerance against both random failure and battery exhaustion from the viewpoint of stochastic node placement. They consider three typical types of stochastic sensor placement: Simple diffusion, Constant Placement and R- Random placement.

In [13] authors studied the problem of determining the critical node density for maintaining k-coverage of a given square region. They have considered three different deployment strategies: Poisson point process, uniform random distribution and grid deployment and have shown that the two random strategies have identical density requirements for k-coverage. They also showed that grid deployment requires less node density than the two random deployments strategies in order to achieve the same level of coverage degree.

In [14] authors perform a performance study for congestion control between three different algorithms under different node placements. Algorithms employ three different techniques for congestion mitigation in WSNs. Source rate reduction, alternative path creation and multipath routing. Results prove that the performance of alternative path creation and multipath routing algorithms is affected by different node placements.

At the same time, lowering the energy requirements of hardware, protocols and algorithms is also a major issue in WSNs. A large volume of research work is related to energy efficiency. Many of them address the problem by defining mechanisms for
scheduling sensing and communication functions. They range from adjusting the connectivity characteristics of nodes [15] to using clustering as an energy saving method [16] and enforcing sleep patterns for energy saving to utilizing heterogeneous power sources [17]. Our work complements these methods, by making sure that adequate communication paths are available and that they are used in an energy efficient way.

III. NODE PLACEMENT ANALYSIS

It is understandable that node density is only one factor that affects network topology. The actual placement of nodes is also significant, as shown in [10] and [18]. Since the placement of nodes affects the ability of a network to correctly sense sense and the number of routes to the sink, the placement of sensor nodes can be proven vital for the improvement of energy utilization performance especially in multipath routing congestion control algorithms. Placement of nodes in a network can be divided in two major categories concerning the way that nodes are placed in the area. These are the deterministic node placement and stochastic node placement. In this work we choose to place nodes in four different placements. Two of the placements are deterministic and the other two are stochastic.

A. Deterministic Node Placement

In deterministic node placement methods, nodes are placed on exact points on the grid or in specific parts of the grid. Usually, deterministic or controlled node placement is specified by the type of nodes, the environment in which the nodes will deploy, and the application. Therefore, in applications like Sensor Indoor Surveillance Systems or Building Monitoring, nodes must be placed manually [10] (either by hand or by robots).

Grid Placement: In this placement nodes are placed strictly on the lines of Grid (Fig. 1a). This placement can, for example, be employed for monitoring the stress on metal beams of a roof (Fig. 1b).

Biased-Random Topology: In this case, topology creation is defined by the field configuration. An example is presented in Fig. 2b where nodes are deployed in the area between two oil tanks.

In this case nodes are spread randomly at predetermined quadrants (deterministic space allocation), where the source and sink are located. The area around the source and sink is densely deployed, able to handle a bigger amount of the network traffic, while the area between the obstacles (e.g. tanks) creates a bottleneck space between them (Fig. 2a).

B. Stochastic Node Placement

Deterministic Placement is not so realistic when many sensor nodes are placed in a large area. In such a situation, stochastic placement is needed.

Simple Diffusion: This node placement emulates the distribution of nodes when they are scattered from air e.g from airplane (Fig. 3a). An example is illustrated in Fig. 3b were nodes are distributed around a sink which is in the center. Simple diffusion is analytically explained in [12].
IV. ALGORITHM DESCRIPTION

A. Hierarchical Tree Alternative Path (HTAP)

HTAP [8] is a distributed and scalable algorithm consisting of four major algorithms.

Flooding with level discovery functionality: This is the initial algorithm used for node discovery once the network has been deployed. This algorithm implements a plain flooding protocol enhanced with level placement function. Through this procedure, each node discovers its neighboring nodes and updates its neighbor table. In addition, through this protocol, sensor nodes are logically placed in levels from the source to the sink.

The Hierarchical Tree Algorithm: In this algorithm a hierarchical tree is created beginning at the source node. Each node is assigned a level according to the hierarchical tree. Connection is established between each transmitter and receiver using a 2-way handshake. Packets are exchanged between each transmitter and receiver in the network, in order to get connected. Through this packet exchange, the congestion state of each receiver is communicated to the transmitter.

Alternative Path Creation Algorithm: During the triggering of an event, the source node begins transmitting data packets creating flows to the sink. In case that a node is receiving more packets that it can transmit (probably from more than one sender simultaneously), its buffer queue will grow and finally the buffer will overflow. To avoid this situation each candidate congested receiver is sending a "high priority" backpressure packet to the sender to inform it that it cannot accept any more packets due to buffer overflow. In this case the sender that received the backpressure packet searches in its neighbor table to find the least congested receiver in order to continue the transmission of data. The alternation of the receivers leads to the creation of new routes from the source to the sink.

Handling of Powerless Nodes (Dead Nodes): Special care is taken in HTAP algorithm for the nodes in which the battery is going to be exhausted. These nodes are possible to cause fatal problems to the network. Thus, when a node is power exhausted, the tables of its neighbor nodes should be updated. This procedure must be as simple as possible due to the fact that this event is more possible to happen when the network is in a crisis state.

B. Directed Diffusion

Directed diffusion [9] is a data centric protocol because all communication is for named data. All nodes in a directed diffusion-based network are application-aware. This enables diffusion to achieve energy savings by selecting empirically good paths (small delay) by caching and processing data in-network (e.g., data aggregation). Directed diffusion consists of four (4) basic elements: interests, data messages, gradients, and reinforcements. An interest message is a query from a sink node to the network, which indicates what the application wants. It carries a description of a sensing task that is supported by a sensor network. Data in sensor networks
is the collected or processed information of an event (e.g. physical phenomenon), is named (addressed) using attribute-value pairs and a sensing task is diffused throughout the sensor network as an interest for named data. This dissemination sets up gradients within the network designed to "draw" events (i.e., data matching the interest). A gradient is direction state created in each node that receives an interest. This direction is set toward the neighboring node from which the interest was received. Events start flowing towards the sinks of interests along multiple gradient paths. To improve performance and reliability, the empirically "good paths" (e.g small delay) are reinforced by the sink and their data rate increases. On the other hand unreliable paths (e.g high delay) are negatively reinforced and pruned off.

V. PERFORMANCE EVALUATION

To evaluate the energy utilization of HTAP and Directed Diffusion under the proposed topologies, a series of simulations has been conducted.

A. Simulation Environment

In all scenarios we chose to deploy nodes within a square area of size 1000m x 1000m. The results presented are the average of 20 runs for each measurement point. In each set of runs, the parameters of Table 1 were kept stable while increasing the number of nodes in the topology to make a dense network with strong connectivity. All nodes in the network have a small buffer able to keep just three packets, thus simulating a congestion situation.

<table>
<thead>
<tr>
<th>TABLE I</th>
<th>SIMULATION PARAMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>X distance (m)</td>
<td>1000</td>
</tr>
<tr>
<td>Y distance (m)</td>
<td>1000</td>
</tr>
<tr>
<td>Transmit Power</td>
<td>600</td>
</tr>
<tr>
<td>Receive Power</td>
<td>600</td>
</tr>
<tr>
<td>Idle Power</td>
<td>50</td>
</tr>
<tr>
<td>Sensitivity Threshold (dBm)</td>
<td>-81</td>
</tr>
<tr>
<td>Path Loss Coefficient</td>
<td>3.5</td>
</tr>
<tr>
<td>Node CPU (MHz)</td>
<td>4</td>
</tr>
<tr>
<td>Radio Freq. (MHz)</td>
<td>433</td>
</tr>
<tr>
<td>Data packet</td>
<td>128 bytes</td>
</tr>
<tr>
<td>Control Packet</td>
<td>50 bytes</td>
</tr>
<tr>
<td>MAC layer</td>
<td>CSMA/CA</td>
</tr>
<tr>
<td>Initial Node Energy</td>
<td>1 Joule</td>
</tr>
</tbody>
</table>

B. Scenario Analysis and Results

1) Network Crash Point: The Network Crash Point is the point at which the network becomes very disconnected (probably because of power exhausted nodes) and communication between source and sink cannot be accomplished anymore. In other words it can be considered as the point where the lifetime of the network ends.

In Fig. 5 we present a comparison of the four deployment strategies concerning the HTAP algorithm with respect to its network lifetime.

HTAP operates extremely well with every examined topology. The algorithm manages to provide an alternative path from the source to the sink, even with more than 80% of

![Fig. 5. HTAP: Number of Power Exhausted Nodes (Network’s Crash Point)](image)

Biased-Random placement exhibits the best results since nodes are massively scattered around source and sink which are the hotspots, providing the ability for multiple path creation around them. Data packets can use these paths to reach the sink, thus avoiding congestion hotspots. Random topology behaves as good as simple diffusion deployment, and is even better than the grid deployment. As it was expected, grid deployment has the worst results (lower crash point) since nodes that are just one hop away from hotspots are limited.

The results concerning the Directed Diffusion Algorithm are presented in Fig. 6. Directed Diffusion depicts a similar, but slightly lower, performance with the HTAP algorithm. Concerning node placements, Directed Diffusion exhibits the best performance with Biased-Random and Simple Diffusion placements and the worst with grid deployment (as HTAP). The reason is also the existence of a plethora of nodes around the source and the sink which provides the ability to this algorithm to reinforce many paths to carry data. So even in the case that some nodes are lost or power-exhausted there are many nodes around the original path to "recover" the communication.

![Fig. 6. Directed Diffusion: Average Number of Power Exhausted Nodes](image)
2) **Average Node Energy**: Massive placements around hot spots (source and sink) can extend a network’s lifetime. This is the result of a more homogeneous energy use from a large number of nodes in the network. In this scenario, while the number of nodes in the network is increasing the number of the injected packets is proportionally increasing, testing the network in heavy load situations.

Fig. 7 presents the average node energy consumption for HTAP algorithm when the traffic rate varies from 100 to 1000 packets/second depending on the number nodes in the network (100 packets/second for 100 nodes, 200 packets/second for 200 nodes etc.) The duration of this simulation is 5 seconds.

As the number of nodes in the network increases, the average energy consumption per node increases, due to the fact that many more packets are injected in the network. This means that the HTAP algorithm is able to safely transmit a big amount of data using almost all nodes in the network, through the creation of alternative paths. When the algorithm runs in the "Biased-Random placement" topology, the network uses the least amount of energy from the network nodes. The reason is that the paths from the source to sink are the shortest, compared to other deployments. This leads to fewer packet exchanges and consequently less power consumption. Concerning Directed Diffusion the results are slightly different (Fig. 8).

Directed Diffusion, exhibits the best results when Simple Diffusion is employed. The reason is that in Simple Diffusion nodes are homogeneously distributed around the sink. This makes it easy for the algorithm to reinforce a relatively increased number of high data rate disjoint paths. On the other hand, in Biased-Random node placement, although nodes around the source and the sink are massively deployed, the bottleneck in the middle of the network, reduces the number of disjoint paths. This fact renders the network unable to handle the increasing number of packets, leading to packet drops and retransmissions, that waste power. This is also the reason that random topology experiences better results compared to Biased-Random when used with Directed Diffusion.

3) **Packet Loss**: The ability of the system to truly support an event-driven sensor network can only be evaluated by the number of packets drops in the network. Fig. 9 provides the number of packet drops per topology for different network sizes. In this graph the most packet drops occur under the "Grid" topology. Packet drops rise when the number of nodes in the network increases. This happens because the nodes near the source and the sink are progressively exhausted due to heavy load. This inevitably leads to packet losses. The same happens under the "Random" topology.

The difference is that, due to the randomness of this method, a largest number of nodes, compared to "Grid" topology lie near the source and sink. On the other hand, "Biased-Random" and "Simple Diffusion" topologies exhibit much better behavior than the previous topologies. The reason is that in these cases, nodes are concentrated in big densities near source and sink. This fact allows the network to react easily in heavy loads since there are plenty of resources at the points of interest. "Simple Diffusion" seems to achieve slightly better results compared to "Biased-Random" since in this topology nodes are spread more homogeneously compared to "Biased-Random". Specifically in "Biased Random", there is a point between the two quadrants that a bottleneck is created. In this case when the load is high these nodes could become...
congested for a small period of time and lose more packets. Concerning Directed Diffusion the results are slightly different (Fig. 10).

In this case as explained before, the network experiences the fewer packet drops when Simple Diffusion Node Placement is employed. On the other hand “Biased Random” placement depicts similar results with random placement (slightly worse). The reason lies, as we explained before, to the big number of packets that are injected in the network and ”Biased Random” placement is not able to handle them.

VI. CONCLUSION

In this paper we present four specific node placements which can alter the energy performance of multipath congestion control algorithms like HTAP and Directed Diffusion. The node placements are: a strictly predetermined placement (grid); a placement in which the deployment areas are predetermined while the nodes are spread randomly in those areas (Biased-Random); a completely random placement (Random) and one with controlled randomness (Simple Diffusion). Simulation results show that the HTAP algorithm can present better results concerning energy utilization when nodes are deployed near hotspots allowing the creation of multiple alternative paths from source to sink (Biased-Random). On the other hand, Directed Diffusion depicts the best results in the placements though which it is able to create the biggest number of reinforced disjoint paths (Simple Diffusion).

Simulation results prove that multipath congestion control routing algorithms exhibit the best performance when the nodes are densely deployed near hot-spots (source and sink). This deployment method can supply the networks with multiple disjoint paths from where data can be routed.

Generally, node placement can be proven as an effective optimization mean for achieving specific performance goals in WSNs like congestion avoidance and energy utilization. Especially for multipath congestion control algorithms dense deployment around hot-spots like sources and sinks, is able to further assist the network to achieve these goals.

ACKNOWLEDGMENTS.

This work has been conducted under the European Union Project GINSENG funded under the FP7 Program (FP7/2007-2013) grant agreement no 224282.

REFERENCES