An Energy Efficient Load-Balanced Multi-Sink Routing Protocol for Wireless Sensor Networks

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Abstract—**One of the most important challenges we must cope with in wireless sensor networks is the energy problem. In these networks, nodes have no unique addresses and are identified by the data gathered by them. Therefore routing is not straightforward considering energy constraints.**

Directed Diffusion is a data-centric routing protocol design for WSNs. Although this protocol adapts well with the situations of WSNs, in the scenarios with the existence of multiple sinks it has some drawbacks. In such cases data is forwarded through all sink nodes imposing the overhead of sending useless data. Our Multi-Sink Directed Diffusion (MSDD) has been introduced to address this problem by forwarding data toward the nearest sink. Also this protocol implements a kind of load-balancing by selecting the next nearest sink after the energy level of nodes in the original path falls below a certain threshold.

Simulation results show that, using our MSDD protocol, connection lifetime between source and sink nodes will be increased up to three times, which is the result of reducing routing overhead of Directed Diffusion protocol.

Keywords - Wireless Sensor Networks; Directed Diffusion; Energy Efficiency; Multi-Sink Routing Protocol; Load-Balancing.

I. INTRODUCTION

In recent years, we have witnessed a growing interest in the field of wireless sensor networks (WSNs) which consist of a large number of micro-sensor nodes, distributed in a large environment to gather and process, specific information required for different applications. In such networks, individual nodes are not particularly important and usually they have not a unique address.

Directed diffusion (DD) [1] is a data-centric routing protocol proposed for data gathering in wireless sensor networks. In DD, attribute-value pairs are used for describing information and data. This algorithm in its basic form has two phases. In the first phase, the sink nodes floods a request packet called "interest" which is consist of the desired attribute-value pairs. When this packet reaches a source node that has the requested information (second phase), It floods an "exploratory data" (ED) packet through the network. When this packet reaches the sink node, it will send a "positive reinforcement" packet toward source node. This packet is being forwarded through the path traversed by the ED packet. In this way, a bi-directional path is constructed between two nodes. Afterwards data packets will be sent through reinforced paths. This algorithm is also called two-phase-pull (TPP) algorithm. By assuming the connections to be bi-directional (which in most cases is not true) One-Phase-Pull [3] (OPP) algorithm can be used. In this approach, data packets are sent immediately after the interest packet reaches the source node. Therefore in OOP algorithm the cost of ED packet flooding will be omitted.

Although this protocol adapts well with the situations of WSNs, in the scenarios with the existence of multiple sinks it has some drawbacks. In such cases all the sinks will receive the exploratory data and reinforces a path toward the source node. Therefore data is forwarded through all sink nodes imposing the overhead of sending repetitive data. In sensor networks, where energy efficiency is of paramount importance, such procedure can adversely impact the lifetime of network. To provide better connection time and implement load-balancing between sinks and sources, it is desirable to find alternative techniques.

Our Multi-Sink Directed Diffusion (MSDD) is introduced to address this problem by forwarding data toward the nearest sink. This selection will lead to packet delivery with minimum energy consumption as minimum number of senders and receivers will participate in the routing process. Also this protocol implements a kind of load-balancing by selecting the next nearest sink after the energy level of nodes in the original path falls below a certain threshold.

Simulation results show that using our MSDD protocol, connection lifetime between source and sink nodes will be increased up to three times which is the result of reducing routing overhead of Directed Diffusion protocol and load balancing technique used in this algorithm.

The rest of this paper will be presented as the following: in the next section some multi-sink routing protocol will be introduced and we compare these protocols with our MSDD approach. In section 3, we will introduce Multi-Sink Directed Diffusion (MSDD) protocol and describe the algorithm in detail. The methodology we used for implementing and testing this protocol is presented in section 4. The simulation results are available in section 5 and a comparison between the original directed diffusion algorithm and our proposed algorithm will be given in this section. Finally we will conclude the paper and present future works to improve our routing algorithm in section 6.

II. RELATED WORKS

Directed diffusion (DD) [1] is a data-centric routing protocol, based on purely local interactions between individual network nodes. This protocol uses application-specific context for aggregation and data dissemination. Therefore it can be completely matched to our application requirements in a large distributed sensor network. So, many works have been recently done to improve the energy efficiency of this protocol and some of them are as the following.

To add location and energy awareness to directed diffusion, GEAR[4] algorithm is introduced. In GEAR queries can be used for a limited area instead of broadcasting interest packet in the whole network area. Passive Clustering [5] uses clustering to reduce overhead of flooding packets in DD by constructing a spanning tree. This tree is used for broadcasting interest packets and in this way, suppresses overhead of transmission of duplicated packets. In EDDD [6] two kinds of gradients are introduced for different applications. For delay sensitive applications, RT (real-time) filters are used and for the remains, BE (best-effort) filters are used for routing.

Directed diffusion forms a single bi-directional path from source toward the sink node. In MDD [7], an extension to DD is presented in order to construct multiple paths between sinks and sources. Using this method, load-balancing is implemented to increase the life-time of the sensor nodes, collaborating in the routing process. MDD (Multi-path directed diffusion) can produce more than one disjoint or braided paths and spread the data collected in the sources, properly between them according to their length and remaining energy. In this way, efficient load balancing can be implemented. In ODCP [8] a local on-demand clustering protocol has been introduced. In this algorithm, early aggregation and limited exploratory data packet flooding can be achieved by using a virtual sink (VS) near the sources. This node plays the role of sink node and broadcasts local interest messages. Therefore the data packets are sent initially to the VS node and then routed toward destination.

Additionally many works have focused on the efficient multiple-sink routing in wireless sensor networks. In [9] an efficient scheme has been proposed for routing data from multiple sources to multiple sinks. This algorithm aims to minimize the link usage in the network by mapping the routing problem to a multi-commodity network design problem. This work tried to send all data to all sinks nodes and so it is different from ours. In [10] a fair capacity sharing method among multiple sinks is introduced. In a multi-sink application scenario, if the sinks produce simultaneous queries, the required traffic may exceed the transmission capacity of certain sensor nodes. In this paper, the capacity of the sensors is shared among multiple sinks in an optimal way by adjusting their query ranges, so that no sensor get congested and every sink is able to monitor an area with desired data rate.

PWave [11] is a multi-source multi-sink anycast routing framework for wireless sensor networks. In this algorithm each node is assigned a potential and sink nodes have the zero potential. This protocol also aims to send all data gathered by sources to all sinks (which differs from our approach) so that minimum number of packets are retransmitted. Also a distributed algorithm is proposed in [12] for minimum energy data gathering in sensor networks with multiple sinks using linear programming optimization method.

III. PROTOCOL DESCRIPTION

Multi-Sink Directed Diffusion routing algorithm is based on the two-phase-pull directed diffusion. In the presence of multiple sink nodes, when an interest packet is received in source that has the interested data, this node broadcasts an exploratory data (ED) packet through the network. This mechanism is used in order to guarantee the packet delivery by the sink nodes because all the connections between the nodes in the path traversed by in interest packet may not be bi-directional. After receiving the ED packet as described in section1, each node reinforces a bi-directional path toward the source node. After receiving each positive reinforcement packet from a neighbor, the source node adds this neighbor to its forwarding list and data is forwarded toward all the sink nodes in this way.

As already mentioned, in WSNs with the limited amount of energy it is important to omit these extra data packets. The simplest idea which arises in mind is to select the first neighbor which has forwarded the reinforcement packet and ignore the additional reinforcement packets. A better idea is to use these extra paths as backup routes and when the energy of nodes in the first path falls below a threshold, use the next path instead. In this way, connection lifetime between source and sink nodes can be increased significantly.

The latter idea is used in MSDD protocol but in order to achieve this goal some modifications need to be made to original directed diffusion. In some cases the path from different sinks may pass from a single neighbor of the source and by using the proposed approach, if this neighbor is selected, data will be forwarded toward all the paths containing that neighbor.

To avoid this problem, path identifiers (path_id) are used for each path by tagging the positive reinforcement packets by each sink node using a random number. So in MSDD each node stores the path_id and the originating neighbor node in table called path_list. Also the path length is computed using a variable (hop_count) included in positive reinforcement packets. This variable is incremented in each hop and when this packet arrives in the source node, hop count can be extracted from this variable for each path. This problem is depicted in figure 1 where paths with path_ids 1 and 2 have a common node. In this figure S represents the source node and D stands for destination or the sink node.

Also in MSDD when a node in a selected path fails due to hardware failure, a negative reinforcement packet is forwarded toward the source node (same as the directed diffusion) leading to exclusion of the failed path from the path_list of the source node. So by using MSDD, resiliency is not reduced in comparison to the directed diffusion.

IV. METHODOLOGY

Designing performance evaluation experiments for wireless sensor networks is faced with a number of practical and conceptual difficulties. The section summarizes our main choices for the simulation setup.

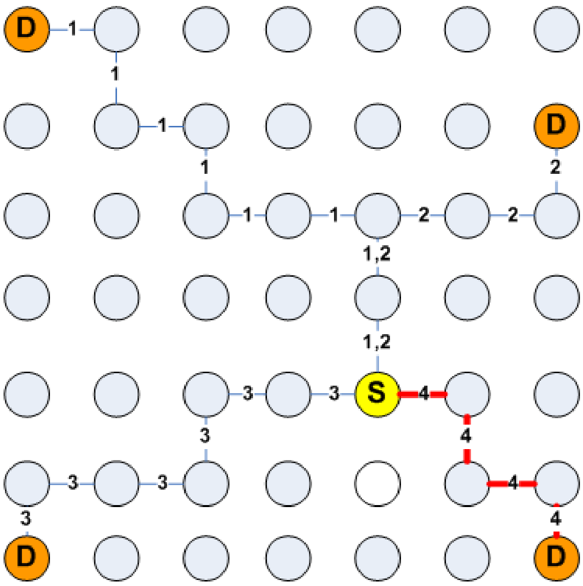


Figure 1. Path selection with minimum Hop Count.

A. Protocol Version

We simulated DD algorithm available with ns-2 simulator, version 2.31. This protocol is implemented for simulator in two versions. We used diffusion3 protocol which is a complete protocol implementation and allows a more realistic evaluation of the protocol [13].

B. Load Model

The traditional DD algorithm floods an interest message every 30 seconds and exploratory data floods every 50 seconds. We used these predefined values in our simulations. In this simulation, we used the ping application as the network traffic with the packet rate of 2 packets per second.

C. Energy Model

In the original directed diffusion, the IEEE 802.11 is used for the MAC layer. For comparability we used the same MAC layer and energy model as in [5] that is the PCM-CIA WLAN card model in ns-2. This card consumes 0.660 W when sending and 0.395 W when receiving. The transmission range is assumed to be constant and 200 meters.

D. Simulation Scenarios

In our approach, for comparison between Directed Diffusion and our On-Demand Proactive Clustering Algorithm, each protocol was tested in a 20*20 grid with the distance of 100 meters between adjacent nodes. For studying the effect of changing number of sink nodes in the efficiency of our protocol we tested two scenarios for energy measurements. In the first case we used 2 sinks and 1 source and in the second case, 5 sinks were used. Following parameters were measured during each scenario: mean energy of network nodes, connection lifetime, drop percentage, routing overhead and number of delivered data packets.

For measuring consumed energy, simulations were run for 400 seconds and remaining energy of all nodes was measured in the period of 25 seconds. In order to calculate overhead and drop percentage, these parameters were measured during 400 seconds using variable number of sources. In another scenario connection lifetime was measured using nodes with initial energy of 5 joules.

Also, in order to highlight the benefits of selection of shortest paths in MSDD, two scenarios have been used; first one selecting the shortest path toward the sinks and another using a random path. Moreover, in these scenarios the effect of increasing the number of sinks also has been studied by using 2 and 5 sinks.

Ping application was used for all scenarios with the packet rate of two packets per second.

E. Energy Calculations

MSDD algorithm aims to decrease the overhead of routing in network nodes by omitting extra data packets.

For measurement of energy-efficiency of MSDD and comparison between MSDD and DD, we used the scenarios, presented in this section. Initial energy of all network nodes assumed to be 5 joules. In our scenarios, the sources start to send ping data packets towards the sink continually, during simulation period (400 seconds) and average energy of nodes were measured each 25 seconds.

F. Connection Lifetime Calculations

For the measurement of energy-efficiency and studying the effect of load-balancing effects on life time of permanent connections between nodes, we used the scenarios, presented in this section. In our simulations, effect of changing of increasing number of sink nodes on the connection lifetime was studied. We assumed the initial energy of all nodes in the network to be 5 joules.

In our scenario, the source starts to send ping data packets toward sink continually until connection is broken due to path node failures caused by energy depletion. This period is measured and considered as connection life-time. The duration between ping packets is assumed to be 0.5 seconds.

G. Overhead and Drop Percentage Computation

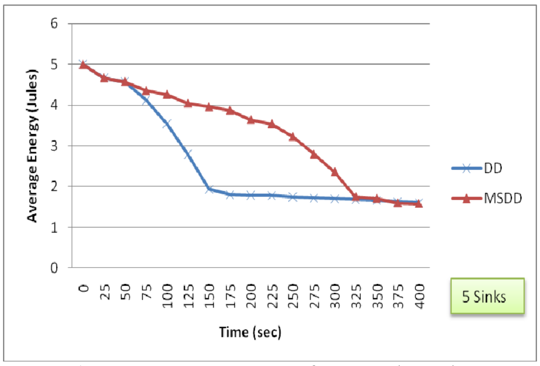
In order to compare overhead and drop percentage between DD and MSDD, these parameters were measured during 400 seconds using variable number of sinks. We measured the number of none-data packets, during the connection time and divided it by the number of received data packets to compute overhead. Drop percentage was measured by dividing number of dropped packets by total number of packets sent.

V. SIMULATION RESULTS

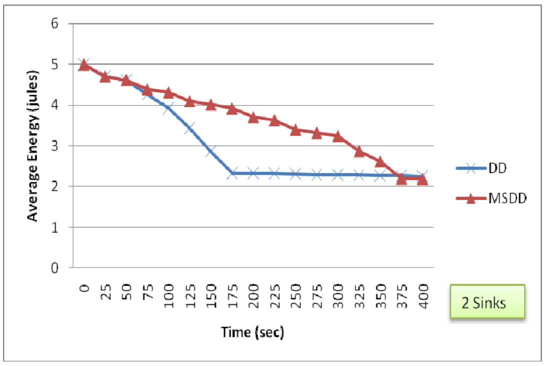
In this section we will show the simulation results, achieved by implementing the scenarios and assumptions, described in the previous section.

A. Average, minimum and maximum node energies

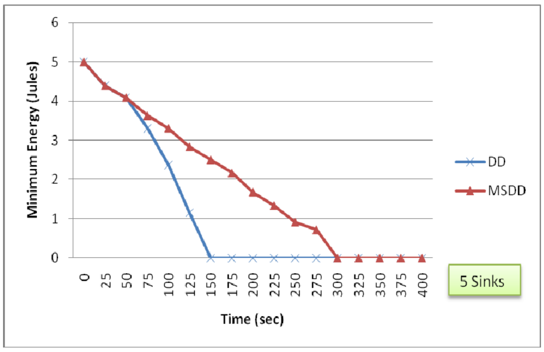
In figure 2 the energy comparison between DD and MSDD has been depicted. As it is obvious, by using MSDD, network energy resources can be used more efficiently. In figures 2.a and 2.b we can see the effect of using different number of sink which shows nearly the same results. So by increasing the number of sink nodes energy efficiency of MSDD does not change significantly.



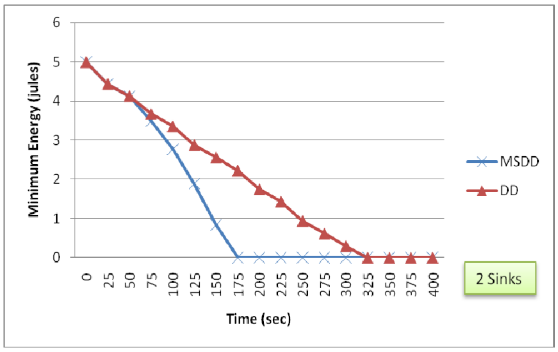
a) Average energy of network nodes



b) Average energy of network nodes



c) Energy of node with the minimum energy



d) Energy of node with the minimum energy

Figure 2. Comparison between energy consumption of DD and MSDD algorithms, a) Comparison between average energy of network nodes in DD and MSDD vs. time using 5 sinks, b) Comparison between average energy of network nodes in DD and MSDD vs. time using 2 sinks, c) Comparison between energy of nodes with the minimum energy in DD and MSDD vs. time using 5 sinks, d) Comparison between energy of nodes with the minimum energy in DD and MSDD vs. time using 2 sinks.

In figures 2.c and 2.d Comparison between energy of nodes with the minimum energy in DD and MSDD vs. time using 5 sinks and 2 sinks has been shown. As we can see, the first dead node using MSDD will endure about twice the time than its equivalent can using DD.

B. Connection Lifetime

The main intention to use MSDD protocol is to increase the efficiency of energy usage and increase the connection lifetime between source nodes and sinks. Figure 3.c shows the comparison between DD and MSDD protocols and demonstrates the effect of increasing number of sink node on the connection lifetime. We can realize from this figure that by increasing number of sink nodes, at first the connection lifetime will be increased (3 sinks in comparison to 2 sinks) but when we use 4 sinks or more, the connection lifetime will be decreased. This can be explained by the overhead of receiving reinforcement packets which increases by the number of sink nodes. However in more dense topologies, increasing the number of sinks will have a more significant effect on the increasing of the connection lifetime.

C. Network Lifetime

In figure 3.b the number of dead nodes in the network is depicted, and if we consider the network lifetime to be the period in which at least half of the nodes in the network are alive, then it can be realized from this figure that by using MSDD instead of using DD protocol, network lifetime will nearly be doubled.

D. Routing Overhead

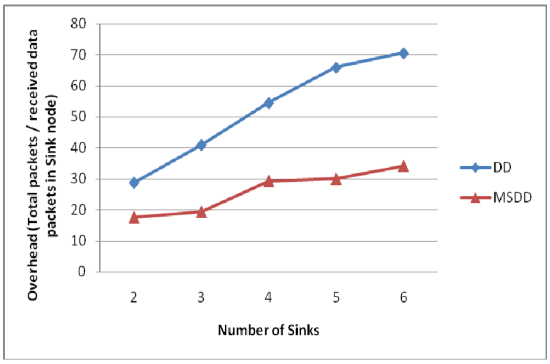
The comparison between routing overhead of DD and MSDD is shown in figure 3.a. This parameter is calculated by dividing total number of packets sent in the routing process by the number of unique packets received in the sink nodes.

E. Number of Delivered Packets

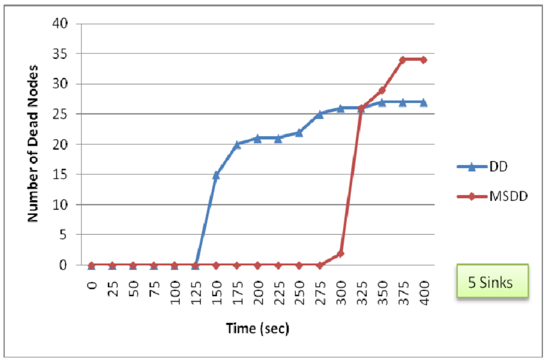
The comparison between routing overhead of DD and MSDD is shown in figure 3.a. This parameter is calculated by dividing total number of packets sent in the routing process by the number of unique packets received in the sink nodes.

F. Shortest Path Selection vs. Random Path Selection

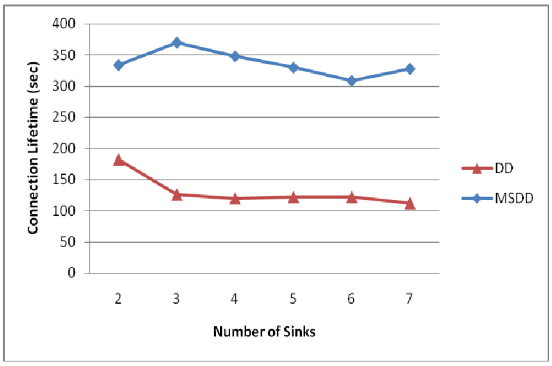
In figure 4, the effect of random path selection instead of shortest path selection is described. In figure 4.a number of dead nodes vs. time between two approaches is compared and in the figure 4.b average node energy comparison is shown. As it can be seen from these figures, selection of shortest path is more energy efficient.



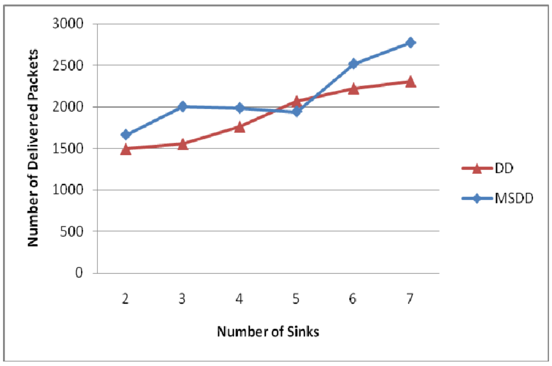
a) Routing overhead vs number of sinks



b) Number of dead nodes vs time



c) Connection lifetime vs number of sinks



d) Number of delivered packets vs number of sinks

Figure 3. Comparison between DD and MSDD algorithms, a) Comparison between overhead of DD and MSDD vs. number of sink nodes; this parameter is calculated by dividing total number of packets sent in the routing process by the number of unique packets received in the sink nodes. b) Comparison between number of dead nodes vs. time in DD and MSDD. c) Comparison between connection lifetime of DD and MSDD vs. number of sink nodes. d) Comparison between number of delivered packets in DD and MSDD vs. number of sink nodes.

VI. CONCLUSION

This paper describes the use of multi-sink routing algorithm (MSDD) for implementing load-balancing and increasing the energy efficiency of the routing algorithm.

The simulation results also prove, using multi-path routing algorithm can lead to longer connection lifetimes up to three times and increase the network lifetime which is the result of reducing routing overhead of Directed Diffusion protocol.

For future work the resiliency of MSDD algorithm can be improved by forcing the sink nodes to send an acknowledgement by receiving the first data packet. Therefore by using a timer in the source node, if the acknowledgement packet is not received after a defined period of time, next path in the path_list can be selected. This period can be estimated by using time stamps in the positive reinforcement packets by their originating sink node and waiting about twice the time needed for forwarding a positive reinforcement packet.

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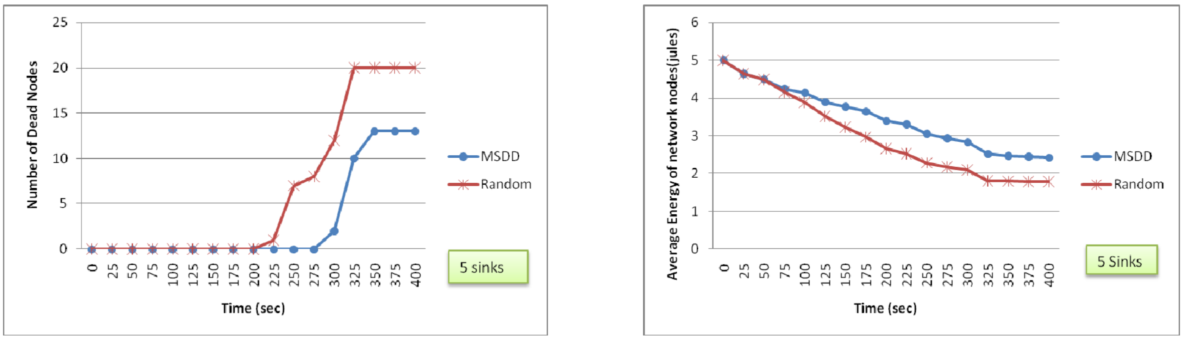

a) Number of dead nodes vs time

b) Avereage node energy vs time

Figure 4. Comparison between energy consumption of DD and MSDD algorithms, a) Comparison between number of dead nodes in DD and MSDD vs. time using 5 sinks, b) Comparison between average energy of network nodes between DD and MSDD vs. time using 5 sinks.

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