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B- α WSP Selection Algorithm: a Load Balancing Convergecast for WSNs

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Abstract—Many-to-one is a common traffic pattern in wireless sensor networks (WSNs), where nodes periodically forward data hop by hop to a single sink. Unfortunately, such communication pattern leads to lose nodes prematurely, especially those located in the sink neighborhood. That phenomenon is essentially due to the high load transit on these nodes, causing a spuriously activation rate comparing to other nodes therefore more energy waste. This is called the funneling effect, which causes also other issues including high delay and packet loss due to the congestion, and collisions. The objective of this work is to reduce the impact of this phenomenon by employing a load-balancing technique in the route selection process. Therefore, we propose the B- α WSP (Balanced- α Weighted Shortest Path) routing algorithm. Simulation results show that our algorithm can effectively reduce the impact of the funneling effect on the nodes activity. Consequently, it reduces the energy consumption and maintains a satisfactory Packet Reception Rate (PRR) comparing to the α WSP algorithm.

Index Terms—Load balancing, WSNs, energy, network lifetime, path cost.

I. INTRODUCTION

While being famous especially for their multiple advantages that justify their presence in various application domains, WSNs have emerged and actually become the academic and industry favorite choice for IoT technologies. However, the energy efficiency is still a challenge in WSNs because of their limited energy resources.

Many-to-one is a common pattern traffic for diverse WSNs applications, that puts challenges to ensure energy efficiency on all the nodes. Mainly because there are only few nodes that can communicate directly to the sink. Consequently, they are more active and they consume more energy.

The objective of this paper is to propose a load balancing strategy that helps in distributing the traffic load among the forwarding nodes. It is mainly inspired by an existing energy efficient routing algorithm called α WSP algorithm [1]. Our main and novelty idea is to assign a *selection factor* to each node during the routing task. Thanks to this parameter, we avoid the overuse of the same nodes each time the transmission is needed. Indeed, we argue that splitting flows may balance the energy consumption across the paths. Simulation results show that the proposed method may enhance both network energy consumption, and packet reception rate.

The reminder of this paper is organized as follows: related works are summarized in the next section. Section III details the α WSP algorithm. Then, the proposed solution is detailed in the Section IV. Moreover, the performance evaluation and the simulation results of the proposed algorithm are discussed

in the section V. Finally, section VI summarizes the paper and presents the perspectives to be investigated.

II. RELATED WORK

The energy balancing problem is especially relevant in large-scale WSNs with the convergecast traffic pattern and static nodes [2]. Due essentially to the diverse consequences of the high traffic transit on the sinks neighbors which leads to limit the application fidelity at the sink [3]. Consequently, there exist in the literature multiple protocols and algorithms which aim to mitigate such problem, as the funnelling-MAC [4]. This latter employs different techniques as the energy balancing due to its ability to reduce the complexity and the cost of the maintenance of WSNs [5].

Our proposed algorithm tackles a static network and aims to optimize its lifetime given a specific topology. As well, it tackles an important issue which is of broad and current interest because of the frequent tree based topology in diverse applications notably the surveillance ones. Moreover, because of the nature of the traffic model in which all generated packets are destined to one sink. This issue is about preserving the lifetime of the direct neighbors of the sink. As mentioned before, our idea is based on an existing routing algorithm which is the α WSP. There are recent works that use the same approach as [6] and [7]. However, the first work uses a two-tier strategy for routing packets in a multimedia WSN which is not the scope of this article. Likewise, the second one aims to preserve the lifetime of the direct neighbors of the sink but uses a DAG structure unlike the present work in which a tree structure is employed.

III. THE α WSP ALGORITHM

In [1] a routing protocol is proposed for WSNs called α WSP Algorithm. In this work, the authors proposed a new energy efficient shortest path tree (SPT) algorithm, based mainly on the measure of the link criticality and the cost path. The most important advantage of this solution is the no need for overhead cost. In other words, there is no need for more control packets. The authors of the α WSP show that the algorithm consumes less energy. Thanks to the proposed cost function which takes into account the concentric convergecast nature of WSN communication. That is carried out by offering a decreasing weight depending on the node level, in addition to the no need to exchange control packets to compute and maintain the path cost.

Although the α WSP algorithm takes from all the mentioned advantages, it suffers from different limits that put challenges to keep the good performance of the network:

i) The selected path, which has the minimal cost, is used for data transfer until the next cost update process is handled. That leads to the quick energy depletion of the nodes belonging to.

ii) The same situation is observed for the direct neighbors of the sink because of the traffic transit on them.

In our proposed algorithm, we aim to update the link cost according to their selection frequency. Additionally, we focus on the link cost instead of the path cost.

IV. THE PROPOSED ALGORITHM

Because of the limitations of the α WSP algorithm that we cited above, here we propose a new variant that we call B- α WSP selection algorithm. For that, we introduce a new parameter named *the selection factor*, which measures the selection frequency of each node. This parameter is updated each time a node is selected as a forwarder. The aim is to give the opportunity to the other possible non-selected forwarders to be selected in the next time.

We assume that the sensor network is composed of static, homogeneous and energy-constrained nodes deployed randomly, with one static base station. In addition, the traffic model is many-to-one. Moreover, the network is mostly-on so there is no duty-cycle plan and it is organized after the setup phase in a tree topology.

Our objective is to balance the traffic transit on the nodes on each hop especially the sink neighbors. To this end, our algorithm runs into two phases. Firstly, during the setup phase, all possible paths between leaf nodes and the sink are computed with their α cost. Then, at the same time, our algorithm associates two parameters: the *factor* and the *selection factor* to each neighbor. The *factor* is initialized to zero while the *selection factor* is initialized to one. Note that the value of the *factor* varies from zero to the number of the existing neighbors of the current node.

Next, if in the routing phase the *selection factor* of a neighbor equals to zero, the node is removed from the list of the potential selected neighbors. While, if there are more than one neighbor, which has the same value of the *selection factor*, the one with the largest path cost is selected. However, when the *selection factor* associated to each neighbor falls to zero, the routing path update is triggered. Hereafter, we present the code of the route update phases of the B- α WSP algorithm. We note by C_{ij} the cost of the $link_{i,j}$, it is updated as follow:

$$B - \alpha cost(P) = selection\ factor * \sum_{k=1}^{k=n} \alpha^{n-k} * C_{ik, ik-1};$$

V. PERFORMANCE EVALUATION AND SIMULATION RESULTS

In order to evaluate the performance of the proposed algorithm, we opted for three criteria: the consumed energy (CE), the packet reception rate (PRR) and the energy depletion rate (EDR). CE refers to the energy consumed by the hole network while PRR refers to the ratio of the number of the successful

Algorithm 1 Route Update Phase

```

1: IF (Sink)
   return;
   else
     best = Null;
     minCost = 0
   Endif
2: While (i < routingTableSize)
   entry = routingTable[i];
   IF (entry.selectionfactor > 0)
     linkCost = alpha * Wj ;
     pathCost = linkCost + Cij ;
     minCost = min(pathCost, minCost);
     best = entry;
   Endif;
 Endwhile;
3: IF (best != NULL)
   ChangeParent(best);
   cost = minCost;
   best.selection-factor = (routingTableSize - best.factor)
   / routingTableSize;
 Endif

```

received packets by the sink and the EDR gives the average of the residual energy in the whole network by a unit of time.

In this section we evaluate the performance of the B- α WSP. To do so, we conducted several simulation experiments using TinyOs [8]. This latter is a wireless sensor network simulator built on nesC language which is a C-dialect integrated with an event-driven execution and stimulating modular design of the embedded applications.

We run five simulations of a WSN having the properties indicated in Table I. Thus, for different network densities value (ND) we present the results for different criteria. In fact, the values shown in the results are averaged over all the runs. Additionally, we analyze the network behavior by measuring the energy depletion rate (EDR) over simulation time. We refer by the network size density (ND) the average number of the neighbor nodes for each node in the network. We adopt 5%, 10% and 15% for ND, because of the machine limits on which we turn our simulator.

TABLE I
SIMULATION PARAMETERS

Parameter	value
Network size	100
Topology	Tree
Tree width	3
Routing table size	16
Data rate	250 Kbits/s

1) *The consumed energy*: Fig1. (a) plots the consumed energy by the sensor network with a different network density, under the B- α WSP Algorithm or the α WSP algorithm. The results reveal that B- α WSP Algorithm saves more energy com-

pared to the α WSP Algorithm for all the proposed scenarios even if the density changes. That is explained by the fact that the forwarders are updated after each data transmission which allows to change between the alternative paths while they are available.

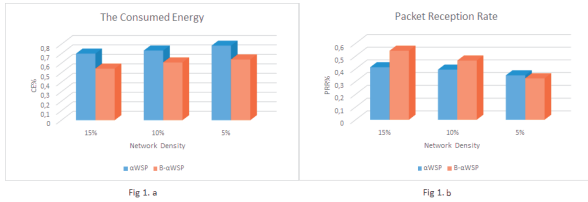


Fig. 1. (a) Energy Consumption (b) Packet reception rate.

2) *The packet reception rate:* Fig1. (b) shows PRR resulting in a sensor network with a different density for each scenario. The PRR parameter was evaluated for both B- α WSP Algorithm and α WSP. It reveals that B- α WSP Algorithm outperforms the α WSP Algorithm in terms of packet reception rate. This is due to the avoidance of the frequent use of the same forwarder, which allows the nodes to cope with node failure and hole problems.

3) *The energy depletion rate:* Figures 2, 3 and 4 plot the energy depletion rate in the network for each network density 5%,10% and, 15%. The figures reveal that the α WSP Algorithm loses energy faster than the B- α WSP Algorithm. For instance, for the case when network density equal to 5%, the α WSP Algorithm loses entirely the energy in 4000s while the proposed algorithm in 6000s. We notice also that for the network density 10% and 15%, the α WSP Algorithm depletes energy before our proposed algorithm (5000s, 4000s) for the α WSP Algorithm and more than 6000s for B- α WSP algorithm.

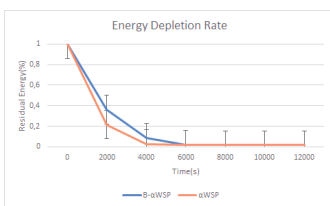


Fig. 2. Energy Depletion Rate with ND=5%.

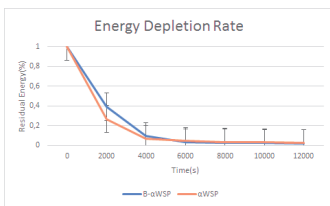


Fig. 3. Energy Depletion Rate with ND= 10 %.

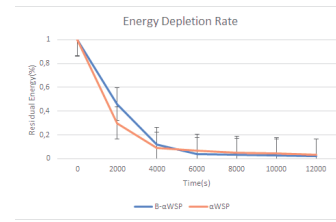


Fig. 4. Energy Depletion Rate with ND= 15%.

In conclusion, it should be noticed that by operating with the B- α WSP Algorithm the WSN stays operating for longer time since it depletes less energy less quickly comparing to α WSP. Moreover, it keeps a good performance by ensuring a better PRR.

VI. CONCLUSION

In this paper, we aim to balance the traffic load between the forwarders. To this end, we proposed the B- α WSP algorithm which takes the routing decision based on three parameters named the node criticality, the residual energy and the node selection factor. Simulation results show that B- α WSP leads to less energy consumption with better packet reception rate (PRR) compared to the α WSP algorithm.

For future work, we are investigating how to extend our algorithm for duty-cycled WSNs. Indeed, it would be an interesting idea because in the present work we considered only mostly-on WSNs.

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