ALBA-R: Load-Balancing around connectivity holes in Wireless Sensor Networks

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Abstract- This paper presents ALBA-R, a protocol for converge casting in wireless sensor networks. ALBA-R features the cross-layer integration of geographic routing with contention-based MAC for relay selection and load balancing (ALBA), as well as a mechanism to detect and route around connectivity holes (Rainbow). ALBA and Rainbow (ALBA-R) together solve the problem of routing around a dead end without overhead-intensive techniques such as graph planarization and face routing. The protocol is localized and distributed, and adapts efficiently to varying traffic and node deployments. We show that ALBA-R significantly outperforms other converge casting protocols and solutions for dealing with connectivity holes, especially in critical traffic conditions and low-density networks. Our results show that ALBA-R is an energy-efficient protocol that achieves remarkable performance in terms of packet delivery ratio and end-to-end latency in different scenarios, thus being suitable for real network deployments.

Keywords– Wireless sensor networks, cross-layer routing, connectivity holes, geographic routing, localization errors

I. INTRODUCTION

DISTRIBUTED sensing and seamless wireless data gathering are key ingredients of various monitoring applications implemented through the deployment of wireless sensor networks (WSNs). The sensor nodes perform their data collection duties unattended, and the corresponding packets are then transmitted to a data collection point (the sink) via multihop wireless routes (WSN routing or converge casting). The majority of the research on protocol design for WSNs has focused on MAC and routing solutions. An important class of protocols is represented by geographic or location-based routing schemes, where a relay is greedily chosen based on the advancement it provides toward the sink. Being almost stateless, distributed and localized, geographic routing requires little computation and storage resources at the nodes and is therefore very attractive for WSN applications. Many geographic routing schemes, however, fail to fully address important design challenges, including 1) routing around connectivity holes, 2) resilience to localization errors, and 3) efficient relay selection. Connectivity holes are inherently related to the way greedy forwarding works. Even in a fully connected topology, there may exist nodes (called dead ends) that have no neighbors that provide packet advancement toward the sink. Dead ends are, therefore, unable to forward the packets they generate or receive. These packets will never reach their destination and will eventually be discarded. Many solutions have been proposed to alleviate the impact of dead ends. In particular, those that offer packet delivery guarantees are usually based on making the network topology graph planar, and on the use of face routing [1]. However, planarization does not work well in the presence of localization errors and realistic radio propagation effects [2], as it depends on unrealistic representations of the network, such as a unit disk graph.

II. RELATED WORK

This study carries a dense networks, this greedy approach is quite successful, since nodes are likely to find a path toward the sink traversing a limited number of intermediate relays. Conversely, in sparse networks, packets may get stuck at dead ends, which are located along the edge of a connectivity hole, resulting in poor performance. A number of ideas have, therefore, been proposed to address the problem of routing around dead ends. Greedy forwarding is typically performed over the virtual coordinate’s space. This decreases the occurrence of dead ends, but does not eliminate them. Topology warping schemes are based on iteratively updating the coordinates of each node based on the coordinates of its neighbors, so that greedy paths are more likely to exist. These approaches are referred to as “geographic routing without location information,” as they do not require accurate initial position estimates.

A. The Rainbow Mechanism and Alba-R

Rainbow, the mechanism used by ALBA to deal with dead ends. The basic idea for avoiding connectivity holes is that of allowing the nodes to forward packets away from the sink when a relay offering advancement toward the sink cannot be found. To remember whether to seek for relays in the direction of the sink or in the opposite direction, each node is labeled by a color chosen among an ordered list of colors and searches for relays among nodes with its own color or the color immediately before in the list. Rainbow determines the color of each node so that a viable route to the sink is always found. Hop-by-hop forwarding then follows the rules established by ALBA. More formally, let x be a node engaged in packet forwarding. We partition the transmission area of x into two regions, called F and FC, that include all neighbors of x offering a positive or a negative advancement toward the sink, respectively (see Fig. 3). When x has a packet to transmit it seeks a relay either in F or FC according to its color Ck,
selected from the set of colors \(fC0; C1; C2; C3; \ldots \). Nodes with even colors \(C0; C2; \ldots\) search for neighbors in \(F\) (positive advancement). Nodes with odd color \(C1; C3; \ldots\) search for neighbors in \(FC\) (negative advancement). Nodes with color \(Ck, k \leq 0\), can volunteer as relays only for nodes with color \(Ck\) or \(Ck+1\). Nodes with color \(Ck, k > 0\), can only look for relays with color \(Ck\) or \(Ck+1\). Finally, nodes with color \(C0\) can only look for relays with color \(C0.3\). The nodes assume their color as follows: Initially, all nodes are colored \(C0\) and function according to the standard ALBA rules (see Section 3). If no connectivity holes are encountered, all nodes remain colored \(C0\) and always perform greedy forwarding. Since the nodes on the boundary of a hole cannot find relays offering positive advancement, after a fixed number \(N_{hh}\) of failed attempts, they infer that they may actually be dead ends and correspondingly increase their color to \(C1.4\). According to Rainbow, \(C1\) nodes will send the packet away from the sink by searching for \(C0\) or \(C1\) nodes in region \(FC\). If a \(C1\) node cannot find \(C1\) or \(C0\) nodes in \(FC\), it changes its color again (after \(N_{hh}\) failed forwarding attempts), becoming a \(C2\) node. Therefore, it will now look for \(C2\) or \(C1\) relays in \(F\). Similarly, a \(C2\) node that cannot find \(C2\) or \(C1\) relays in \(F\) turns \(C3\) and starts searching for \(C3\) or \(C2\) nodes in \(FC\). This process continues until all nodes have converged to their final color. Note that, at this point, any node that still has color \(C0\) can find a greedy route to the sink, i.e., a route in which all nodes offer a positive advancement toward the sink. In other words, once a packet reaches a \(C0\) node, its path to the sink is made up only of \(C0\) nodes. Similarly, packets generated or relayed by \(Ck\) nodes follow routes that first traverse \(Ck\) nodes, then go through \(Ck+1\) nodes, then \(Ck+2\) nodes, and so on, finally reaching a \(C0\) node. As soon as a \(C0\) node is reached, routing is performed according to ALBA greedy forwarding. A sample topology where four colors are sufficient to label all nodes is given in Fig. 4. In the figure, the numbers in the nodes indicate the color they assume. Higher colors are rendered with darker shades of gray. A proof of the correctness of the Rainbow mechanism is given in the supplemental material document, available online. That proof, including convergence of the coloring mechanism in finite time and the loop-freeness of the determined routes, is performed through mathematical induction on the number \(h\) of changes of color in the route from a node to the sink. ALBA-R correctness is not affected by the presence of localization errors or by the fact that the topology graph is not a UDG, showing that our protocol is robust to localization errors and realistic propagation behaviors.

III. PROPOSED SCHEME OF WORK

I had proposed an approach to the problem of routing around connectivity holes that works in any connected topology without the overhead and inaccuracies incurred by methods based on topology planarization. Specifically, we define a cross-layer protocol, named ALBA for Adaptive Load-Balancing Algorithm, whose main ingredients (geographic routing, load balancing, contention based relay selection) are blended with a mechanism to route packets out and around dead ends, the Rainbow protocol. The Rainbow mechanism allows ALBA-R to efficiently route packets out of and around dead ends. Rainbow is resilient to localization errors and to channel propagation impairments. It does not need the network topology to be planar, unlike previous routing protocols. The framework takes into account the self-interference of flows and assigns (a) channels (b) transmission power levels and (c) time slots to each link such that the objective is achieved. Available neighboring nodes respond with clear-to-send (CTS) packet carrying information through which the sender can choose the best relay. Energy provide with the flow of path. ALBA mechanism performs load balancing based on splitting of packets, key generation and signature on data. The splitting of packets is based on number of inputs. ALBA-R is an energy-efficient protocol that achieves remarkable performance in terms of packet delivery ratio and end-to-end latency in different scenarios.

ALBA-R on Sparse Topologies: This set of experiments concerns the performance of Rainbow. We only consider ALBA-Rh, \(h \leq 0\); \(1\); \(1\). ALBA-R0 being ALBA without Rainbow, ALBA-Rh, \(h > 0\), being ALBA-R where nodes cannot change color after reaching color \(Ch\), and ALBA-R1 being ALBA-R as described. Results refer to scenarios with 100 and 200 nodes. Each node has a limited number of neighbors (sparse networks), dead ends occur, and greedy forwarding has been shown to fail often. For example, with 200 nodes, only about half of the nodes are colored \(C0\) and can, therefore, greedily deliver packets to the sink. This percentage falls to 10 percent in topologies with 100 nodes.

The average packet delivery ratio, the end-to-end packet latency, the normalized energy consumption per node, and the normalized overhead incurred by ALBA-Rh, for \(h \leq 0\); \(1\); \(1\). For \(h \leq 1\), all packets are delivered to the sink (except at very high load, due to congestion). However, from Fig. 7a, we note that a few colors suffice to greatly improve the packet delivery ratio: 99 percent (74 percent) of the generated traffic is correctly delivered when \(n \leq 200\) (\(n \leq 100\)), and \(h \leq 1\). By way of contrast, in ALBA-R0, this percentage decreases to 85 percent (48 percent) or less. It may seem counter-intuitive that the percentage of the packets discarded by ALBA-R0 is higher than the average percentage of non-\(C0\)nodes. This is because \(C0\) nodes may send some of their packets to nodes leading to dead ends; such packets will ultimately get stuck, since in ALBA-R0, no node coloring (and subsequent packet rerouting) takes place.

IV. PERFORMANCE EVALUATION

A. Simulation Scenarios and Metrics

All investigated protocols have been implemented in the ns2 simulator [29]. We used the simulator Friis propagation loss model. The transmission power has been set to achieve successful delivery to nodes within a distance equal to the selected transmission range. The MAC layer is based on CSMA/CA with energy Rainbow with Rotational Sweep, the dead end handling mechanisms presented in [6]. We implemented both delay functions: Sweep Circle and Twisting.
Triangle. Finally, the performance of ALBA-R in networks affected by localization errors. All our results have been obtained by averaging the outcomes of 100 simulations, each running for 30,000 s, each time on a different connected topology. The resulting confidence interval of our results has a width within 5 percent of the value shown. Since we are interested in steady-state performance, all metrics have been collected after 1,200 s from the start of each simulation run.

We have investigated the following metrics: the normalized node energy consumption, defined as the ratio between the total energy consumed by all nodes over a given time and the energy that the nodes would consume by strictly following the duty cycle, if there were no packets to transmit and receive; the per packet energy consumption, defined as the average amount of energy spent by all nodes to successfully deliver a packet to the sink; the packet delivery ratio, defined as the fraction of packets that are successfully delivered to the sink; and the end-to-end latency, defined as the time from packet generation to its delivery to the sink. The latter metric is computed only for successfully delivered packets.

We perform three sets of experiments. The first set concerns moderately high-density network scenarios, where dead ends do not occur (higher density results are shown in the supplemental material document, available online). In this setting, we compare the performance of ALBA to that of other cross-layer protocols specifically designed for high-density WSNs. We consider networks within nodes, where \( n = \{100, 200, 600\} \). The sensors are randomly and uniformly deployed in a square area of size 320 m². The node transmission range is set to 40 m.

Therefore, the average degree of a node ranges between 5 and 30 nodes, which span a wide range of realistic values. Nodes go to sleep and wake up according to independent awake-asleep schedules with a fixed duty cycle \( d = \frac{4}{13} \). The energy consumption when transmitting, receiving, and when in sleep mode follows the first-order energy model described in [30]. The energy ERX consumed for receiving a bit is constant, while the energy consumed for transmitting a bit, transmitter circuitry (and is set equal to ERX). "a r models the energy required to cover the transmission range r. We choose the value of "a as in [30]. The energy cost when in sleep mode is a very low, nonzero value, that we set equal to \( 1 = 1; 000 \) of the energy spent for receiving. According to this energy model, ETXa>ETXe for \( r > 22.5 \) m.

Data traffic is generated according to a Poisson process of intensity packets per second over the whole network. Each packet is randomly and uniformly assigned to a source, excluding nodes that are one hop from the sink. The chosen source queues the assigned packets and transmits them as soon as possible. The maximum queue length per node is set to 20 packets. A newly generated packet is accepted by the source only if its buffer is not full. The traffic rate varies from 0.25 to 6 packets per second. Data packets are all 250B long. The length of control packets is 25B. The channel data rate is 38.4 kbps. ALBA parameters and MB have been set.

Effectiveness of Rainbow in dealing with connectivity holes is demonstrated on scenarios with dead ends (sparse networks).

V. RESULT

I had employed the performance of ALBA-R, a cross-layer scheme for convergecasting in WSNs. ALBA-R combines geographic routing, handling of dead ends, MAC, awake-asleep scheduling, and back-to-back data packet transmission for achieving an energy-efficient data gathering mechanism. To reduce end-to-end latency and scale up to high traffic, ALBA-R relies on a cross-layer relay selection mechanism favoring nodes that can forward traffic more effectively and reliably, depending on traffic and link quality. Results from an extensive performance evaluation comparing ALBA-R, GeRaF, and IRIS show that ALBA-R achieves remarkable delivery ratio and latency and can greatly limit energy consumption, outperforming all previous solutions considered in this study. The scheme designed to handle dead ends, Rainbow, is fully distributed, has low overhead, and makes it possible to route packets around connectivity holes without resorting to the creation and maintenance of planar topology graphs.

Rainbow is shown to guarantee packet delivery under arbitrary localization errors, at the sole cost of a limited increase in route length. The comparison with Rotational Sweep, a set of recently proposed mechanisms for avoiding connectivity holes, shows that Rainbow provides a more robust way of handling dead ends and better performance in terms of end-to-end latency, energy consumption, and packet delivery ratio. Testbed experiments have validate.

VI. CONCLUSION AND FUTURE WORK

We presented we have proposed and investigated the performance of ALBA-R. A cross-layer scheme for convergecasting in WSNs. ALBA-R combines geographic routing, handling of dead ends, MAC, awake-asleep scheduling, and back-to-back data packet transmission for achieving an energy-efficient data gathering mechanism. To reduce end-to-end latency and scale up to high traffic, ALBA-R relies on cross-layer relay selection mechanism favoring nodes that can forward traffic more effectively and reliably, depending on traffic and link quality. Results from an extensive performance evaluation comparing ALBA-R, GeRaF, and IRIS show that ALBA-R achieves remarkable delivery ratio and latency and can greatly limit energy consumption, outperforming all previous solutions considered in this study. The scheme designed to handle dead ends, Rainbow, is fully distributed, has low overhead, and makes it possible to route packets around connectivity holes without resorting to the creation and maintenance of planar topology graphs.
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REFERENCES


