Adaptive Dynamic Connectivity Hole Load-Balancing Geographic Routing in Wireless Sensor Network

R.Mohanapriya[1] Mrs.V.Vennila[2]
[1]Student of M.E [2]Assistant Professor
[1,2]Department of Computer Science & Engineering
[1,2]K.S.R. College of Engineering, Namakkal, Tamil Nadu-637215, India

Abstract— To detecting connectivity failure around the wireless sensor network by using Adaptive Load-Balancing Algorithm (ALBA) for find the solution to identify the localization errors. Rainbow mechanism is used to differentiate grouping nodes using various colours. Both Adaptive Load-Balancing Algorithm and Rainbow mechanism are detects connectivity holes in network, a protocol for convergecasting 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. The ns2-based simulation, Hole Healing Algorithm is introduced for overcome these drawbacks in wireless sensor networks. The solution is dealing with connectivity holes, especially in critical traffic conditions and low-density networks.

Key words: Wireless sensor networks, cross-layer routing, connectivity holes, geographic routing, localization error

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) routingaroundconnectivity 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. However, planarization does not work well in the presence of localization errors and realistic radio propagation effects, as it depends on unrealistic representations of the network, such as a unit disk graph.

To propose 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 ingre- dients (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 combination of the two protocols, called ALBA-R, results in an integrated solution for converge casting in WSNs that, although connected, can be sparse and with connectivity holes. The contributions we provide to WSN research with this paper include the following:

Extensive ns2-based simulation experiments are performed that demonstrate how the unique features of ALBA-R determine its overall performance, and that show its superiority with respect to previous exemplary solutions for geographic-based and topology-based converge casting, such as GeRaF and IRIS. We have also investigated the performance of Rainbow in sparse networks, where dead ends are likely to occur, with and without localization errors. We show that Rainbow is an effective distributed scheme for learning how to route packets around connectivity holes, achieving remarkable delivery ratio and latency performance. Our simulation results also show better performance than that of two recent proposals for routing around dead ends.

The critical metrics of packet delivery ratio and end- to-end (E2E) latency are further investigated through experiments in an outdoor 40-node testbed of TinyOS-based sensor nodes. Besides validating our simulation model, the obtained results confirm the effectiveness of ALBA-R in supporting long-lived and reliable wireless sensor networking in practice. A succinct version of this paper has appeared. The current version presents a considerably larger set of experiments and comparisons with previous solutions.

II. Related work

According to its first and simplest formulation, geographic routing concerns forwarding a packet in the direction of its intended destination by providing maximum per-hop advancement. In 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. . WSN topologies are first "planarized". Geographic routing over planarized WSNs is then obtained by employing greedy routing as long as possible, resorting to planar routing only when required, for example, to get around connectivity holes. Heuristic rules are then defined for returning to greedy forwarding as soon as next-hop relays can be found greedily. Solutions based on planarization have several drawbacks. First of all, a spanner graph of the network topology needs to be built (and maintained in the presence of node dynamics), and this incurs non- negligible overhead. Planar routing may then require the exploration of large spanners before being able to switch back to the more efficient greedy forwarding, thus imposing higher latencies. Moreover, in realistic settings, localization errors and non-ideal signal propagation may lead to disconnected planar graphs or to topology graphs that are non-planar. To make planarization work on real networks, a form of periodic signaling must be implemented to check that no links cross, as performed by the Cross-Link Detection Protocol (CLDP). However, this is a transmission-intense solution for WSNs, which eventually affects the network performance. For a comprehensive overview of planar graph routing, the reader is referred to the survey by Frey. A different class of solutions for handling dead ends is based on embedding the network topology into coordinate spaces that decrease the probability of connectivity holes. This category includes algorithms using virtual coordinates, and those that perform some sort of topology warping. In the former case, the coordinates of each node are the vector of the hop distance between the node and each of a set of beacons. Greedy forwarding is typically performed over the virtual coordinates 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. Both methods, however, present a non-negligible probability that packets get stuck in dead ends.

III. THE ADAPTIVE LOAD-BALANCING ALGORITHM

The protocol we propose in this paper, ALBA, is a cross-layer solution for convergecasting in WSNs that integrates awake/asleep schedules, MAC, routing, traffic load balancing, and back-to-back packet transmissions. Nodes alternate between awake/asleep modes according to independent wake-up schedules with fixed duty cycle d. Packet forwarding is implemented by having the sender polling for availability its awake neighbors by broad- casting an RTS packet for jointly performing channel access and communicating relevant routing information (cross-layer approach). Available neighboring nodes respond with clear-to-send (CTS) packet carrying information through which the sender can choose the best relay.

Relay selection is performed by preferring neighbors offering "good performance" in forwarding packets. Positive geographic advancement toward the sink (the main relay selection criterion in many previous solutions) is used to discriminate among relays that have the same forwarding performance. Every prospective relay is char- acterized by two parameters: the queue priority index (QPI), and the geographic priority index (GPI). The QPI is calculated as follows: The requested number of packets to be transmitted in a burst (back-to-back transmissions) isNB, and the number of packets in the queue of an eligible relay is Q. The potential relay keeps a moving average M of the number of packets it was able to transmit back-to- back, without errors, in the last forwarding attempts.

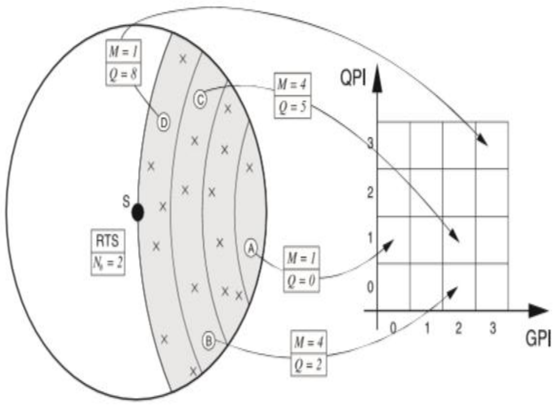

Fig. 1: Computing QPI and GPI values.

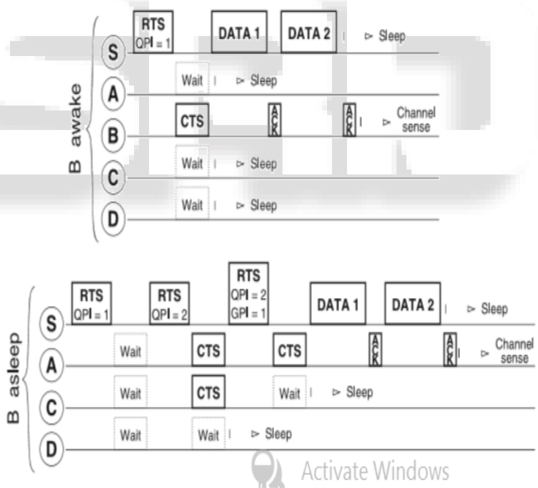

Fig. 2: ALBA handshakes.

In our implementation, the computation of M is made easier by having the receiver acknowledge separately every packet of the burst with QPI ¼ 1 are allowed to answer the first RTS with a CTS packet. If nobody answers, other RTS packets are broadcast calling for answers by nodes having an increasingly higher QPI. To select the node with the best GPI, a new RTS packet is broadcast calling for answers only from nodes whose GPI is 0, i.e., from nodes providing the highest advancement. If no nodes are found, successive RTS are broadcast calling for nodes with progressively higher GPI. Further ties from multiple nodes replying with the same (QPI,GPI) pair are broken by a binary splitting tree collision resolution mechanism. This relay selection process can fail in two cases: 1) If no node with any QPI is found, or 2) if the contention among nodes with the same QPI and GPI is not resolved within a maximum number of attempts NMaxAtt. Both situations cause the sender to back off. If the sender backs off more than NBoff times, the packet is discarded. Let us assume that node B is awake and that it is the only available relay whose QPI is 1 after the first RTS (upper part of Fig. 2; all other neighbors are asleep). Node B replies to S with a CTS and is selected as a relay. In the case when B is asleep (lower part of Fig. 2), only A, C, and D would be available. In this case, no node with QPI equal to 1 exists, so that the first RTS is not answered. Both A and C answer the second RTS, as both have the QPI equal to 2.

The second phase (best GPI search) is then started, which terminates with the selection of node A, whose GPI is equal to 0. Once a relay is selected, a burst of data packets is sent (as many as the relay can queue, up to NB), and each packet is individually acknowledged. If the ACK for one of the packets is missing, the sender stops the transmission of the burst, rescheduling the unacknowledged packet and the following ones in the burst for a later time, after a back off period. The sender updates its expected maximum burst length M, by taking into account the number of correct packets that have been received (if errors occurred), or by optimistically assuming that a certain burst of length MB packets was received correctly, even if NB <M B (in case of no errors). MB is a tunable protocol parameter limiting the maximum number of packets that can be transmitted back-to-back in a burst. Nodes that lost the contention overhear data transmissions, understand from the header that they have not been selected as relays, and go back to sleep. Similarly, the nodes that during a handshake realize that they will not be selected as relays go to sleep immediately. We have observed that significant performance improvements can be obtained by allowing awaking nodes to join a relay selection phase that has already started. Upon waking up, nodes enter the QPI search phase and can answer an RTS packet with CTS, provided their QPI index is lower than or equal to the one that is currently being searched for. When a nonempty QPI region is queried and one or more eligible forwarders answer the RTS, the best GPI search starts, and the set of eligible forwarders is frozen (no node that wakes up after this time can enter the contention). This choice has been made to favor a fast relay selection once a region with active neighbors has been found.

IV. HOLE HEALING ALGORITHM WITH ALBA-R

In this section, we describe Rainbow, the mechanism used by ALBA to deal with dead ends. The basic idea for avoiding connectivity holes by using Hole Healing Algorithm that of allowing the nodes to forward packets away from the sink when a relay offering advancement toward the sink cannot be found. 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;...

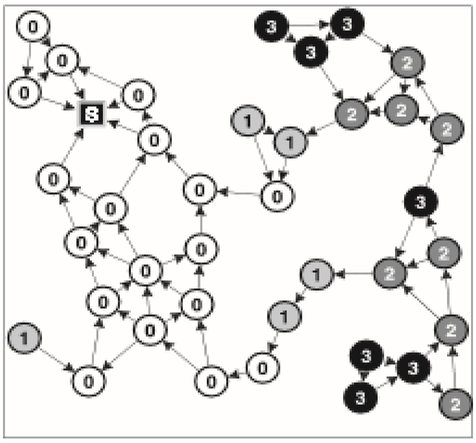

Fig. 3: Rainbow coloring.

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 Ck1 nodes, then Ck2 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 mechan- ism in finite time and the loop-freedom 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.

V. PERFORMANCE EVALUATION

Simulation Scenarios and Metrics All investigated protocols have been implemented in the ns2 simulator. 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 levels and packet reception thresh- olds typical of carrier sensing. We consider networks with n nodes, where n ranges in {100,200,600}. The sensors arerandomly and uniformly deployed in a square area of size 320*320 m. The node transmission range is set to 40 m. Therefore, the average degree of a node ranges between 5 and 30 nodes, which spans 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 ¼ 0:1. The energy consumption when transmitting, receiving, and when in sleep mode follows the first-order energy model. The energy ERX consumed for receiving a bit is constant, while the energy consumed for transmitting a bit is energy needed by the transmitter circuitry the 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, ETXaðrÞ>ETXe for r>22:5m. 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.

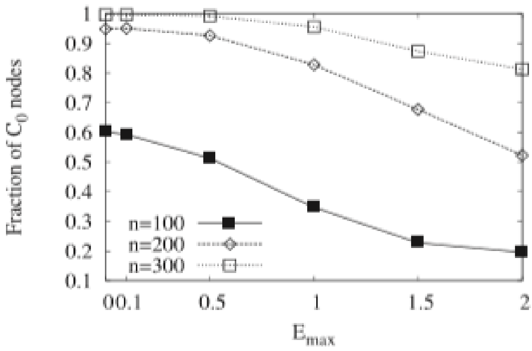

Fig. 4: C_0 nodes for increasing localization errors

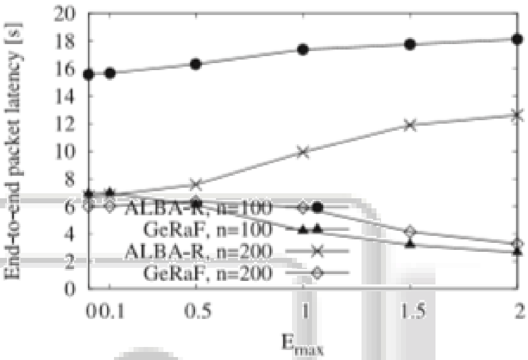

Fig. 5: End to End Latency

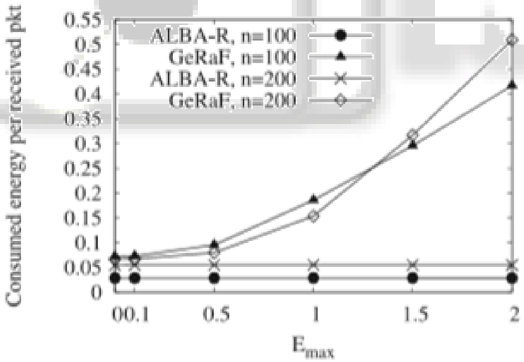

Fig. 6: Energy Consumption

VI. CONCLUSIONS

The proposed hole healing algorithm is used to solve the connectivity hole problem 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 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.

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