

Energy-Efficient Self-Organization in Wireless Sensor Networks

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Abstract—The concept of self-organization defined as global behavior emerging from local interactions [1] is applied to multi-hop wireless networks. Because of their specific constraints, self-organizing solutions for ad-hoc networks can not be applied as such to Wireless Sensor Networks. Solutions for ad-hoc networks often include some form of clustering. Yet, building and maintaining such a structure seems too energy consuming in the context of low-power low-throughput wireless sensor networks.

Geographic-routing protocols do not maintain a structure, but still can guarantee delivery. Moreover, as the radio interface accounts for most of the energy depleted in a sensor, it is essential to couple this layer 3 protocol with an energy-efficient MAC protocol. The goal of this paper is to present the resulting energy efficient cross-layered self-organizing architecture.

I. INTRODUCTION TO WIRELESS SENSOR NETWORKS

A Wireless Sensor Networks (WSN) is composed of a large number of nodes capable of doing three complementary tasks: measuring a physical value, processing that value and communicating wirelessly. WSNs form a link between the physical and the computational worlds, with applications ranging from the military to Health and intelligent homes [2].

In a forest fire detection scenario, nodes may be dropped by a helicopter into the to-be-monitored area. This implies that nodes have random locations, and that human intervention on each individual node can not be count on. This is especially restricting for energy, as batteries can not be replaced.

There is no fixed infrastructure in a WSNs (such as 802.11-like access points). Moreover, even though nodes are considered static, the dynamics of the links and the fact that nodes

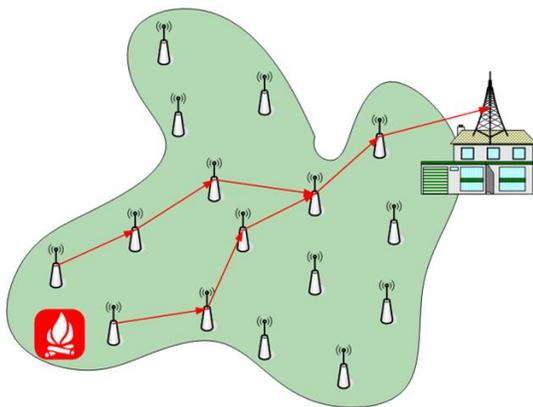


Fig. 1. A forest fire detection scenario. A fire is detected by at least one sensor. The resulting alarm messages are sent to a collecting node in a multi-hop fashion.

may appear/disappear causes the topology to change. Finally, as depicted in Fig. 1, communication is done in a multi-hop way. As the individual radios of the nodes are not powerful enough to send a message directly to the sink, intermediary nodes are used as relays.

The three previous points characterize ad-hoc as well as wireless sensor networks. Yet, major differences exist: (1) energy is a very scarce resource in a WSN (2) the flow of information follows a many-to-one pattern rather than a one-to-one common in ad-hoc networks and (3) a WSN is essentially low-throughput.

II. DIFFERENT SELF-ORGANIZATION APPROACHES

Self-organization can be defined as the emergence of a global behavior from local interaction [1]. In a multi-hop wireless network scenario, nodes do not know anything a priori about the network, so bringing some form of structure is necessary. Solutions may be very different depending on the application and the constraints applied to the network.

In an ad-hoc network, composed for example of highly mobile hand-held personal digital assistants, this structure is usually a clustered one. Clustering consists of grouping close node together. A clusterhead can then be used to lead each cluster, and to serve as a inter-cluster gateway. Clustering typically involves discovering the neighbors, forming clusters, interconnecting those clusters and running some sort of hierarchical routing protocol on top of this structure (please refer to [3] for details). Because of the network dynamics, once built, this structure needs to be maintained. With an up-to-date structure, it is possible to deploy services such as finding the closest printer or vending machines.

We argue that these types of solutions are not very well-fit for a WSN. First of all, in the example of Fig. 1, the networks sits idle for most of the time. Without any useful traffic transiting on the network, maintaining a structure is pure overhead. What's more, a WSN is very application specific and it's goal is limited to conveying a message from source to destination. This basic goal may be achieved without the need of a complex clustered structure.

III. A CROSS-LAYERED SELF-ORGANIZING COMMUNICATION ARCHITECTURE FOR WSN

Cross-layering is about having different communication layers exchange information so as to optimize the overall energy expenditure. This is a key concept when aiming at true

energy-efficiency. For the ease of understanding, we describe our solution layer by layer. We invite the interested reader to refer to the cited papers.

A. 1-hopMAC to avoid maintaining a neighborhood tables

In a multi-hop network, most routing protocols assume that each node maintains a neighbor list. This is traditionally done by periodically exchanging Hello messages. This approach suffers from (1) depending on the period, neighborhood information may be outdated when needed and (2) each node depletes energy even though the network sits idle.

Based on [4], we have proposed the 1-hopMAC protocol. This protocol retrieves neighborhood knowledge in an on-demand fashion. Moreover, as it is based on preamble-sampling, the usage ratio can be as low as 1% when no useful traffic is transiting on the network. Details can be found in [5].

B. Geographic Forwarding with Loose Position-Awareness

In most applications envisioned for WSNs, a message becomes really useful when the user knows where it came from. Therefore, having location-aware nodes is not unrealistic. The location information contained in each node can be used for routing purposes. The simplest greedy approach consists of asking a node to send a message to its neighbor which is closest to destination.

Whereas this approach may fail, Bose et al. have proposed GFG, which uses the right hand rule to circumnavigate the void area responsible for this failure [6]. A major drawback of this approach is that it assumes perfect location-awareness. It can be shown that under limited location accuracy (for example the 10m accuracy provided by the popular GPS positioning system), GFG fails.

To answer this drawback, we propose to record the sequence of nodes traversed by a packet into this packet, and to use this information for routing. We have derived three rules which need to be used by nodes in order for the packet to perform a depth-first tree search. We show in [7] that our protocol achieves a 100% delivery guarantee while having a hop count similar to the one of GFG (see Fig. 2).

IV. CURRENT AND FUTURE WORK

For our communication architecture to be complete, it is necessary to study the physical layer, and to identify possible cross-layering opportunities. We are currently implementing a realistic propagation model into our simulation platform. Moreover, we are investigating on cooperative communication. In a cooperative scheme, individual nodes are coupled together to form a virtual antenna array. This MIMO-like structure achieve better signal-to-noise ratios while reducing the energy consumptions of the node. Yet, it is not clear whether a cooperative scheme can be easily applied to WSNs, and if so, what the benefits would be.

As future work, we would like to obtain a truly cross-layered energy-efficient self-organized communication architecture for WSNs. We would like to confront the analytical evaluation of

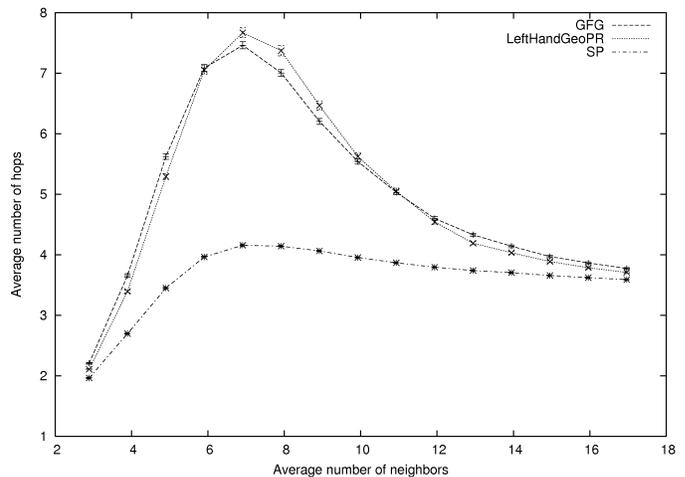


Fig. 2. Whereas our solution (LeftHandGeoPR) does not perform significantly better in term of number of hops that GFG, we do not assume that node know their position with infinite accuracy. Details can be found in [7].

our solution with simulation results. We are also planning to implement our protocol stack on a WSN platform which is currently being developed at France Telecom R&D.

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