Poster Abstract: Communication in Extreme Wireless Sensor Networks

Marco Cattani Marco Zuniga Matthias Woehrle Koen Langendoen

Embedded Software Group
Delft University of Technology, The Netherlands
{m.cattani, m.zuniga, m.woehrle, k.g.langendoen}@tudelft.nl

1. INTRODUCTION

In spite of using unreliable resource-constrained devices, sensor networks can nowadays deliver 99.9% of their data with duty cycles well below 1%. This remarkable performance is, however, dependent on one or more of the following assumptions: low traffic rates, medium size densities and static nodes.

In this poster, we investigate the performance of the same resource-constrained devices, but under scenarios that present extreme conditions in all the aforementioned characteristics.

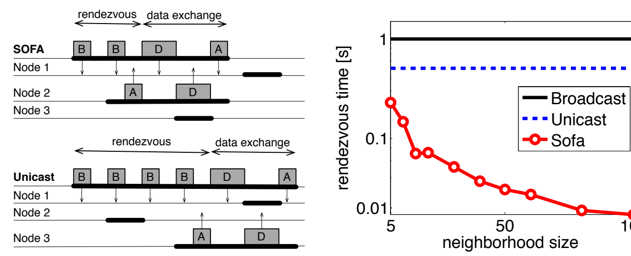
Our work is motivated by an application related to public safety: the need to monitor the density of crowds in open-air festivals. As a part of a larger project[1], we plan to equip the participants with a compact sensing device, creating networks consisting of thousands of mobile entities with hundreds of neighbors that need to disseminate information across a network with minimal energy and at a relatively high rate (a packet per node every few seconds).

In these Extreme Wireless Sensor Networks (EWSN), we can not rely on communication protocols that are centralized or that require synchronization. Such mechanisms often require a stable network topology, information about the neighbors' scheduling [3] or a network with limited diameter [4]. To provide a communication service in such extreme conditions we need a system that is asynchronous, stateless and fully distributed.

Unfortunately, asynchronous techniques [2, 6], designed for low data rates, collapse under the traffic demands of EWSN. Due to their low duty cycle, most of the nodes' resources are used to rendezvous (to be awake at the same time) instead of communication. In order to scale to EWSN, where nodes send a message every few seconds, it is essential that this rendezvous phase is reduced to the minimum.

[1] This work is supported by the COMMIT/ research program and, in particular, is part of the EWiDS project (very large wireless sensor networks for well-being).

SenSys '13, Nov 11-15 2013, Roma, Italy
ACM 978-1-4503-2027-6/13/11.
http://dx.doi.org/10.1145/2517351.2517417



(a) Mechanism (b) Rendezvous time

Figure 1: Comparison between unicast and SOFA

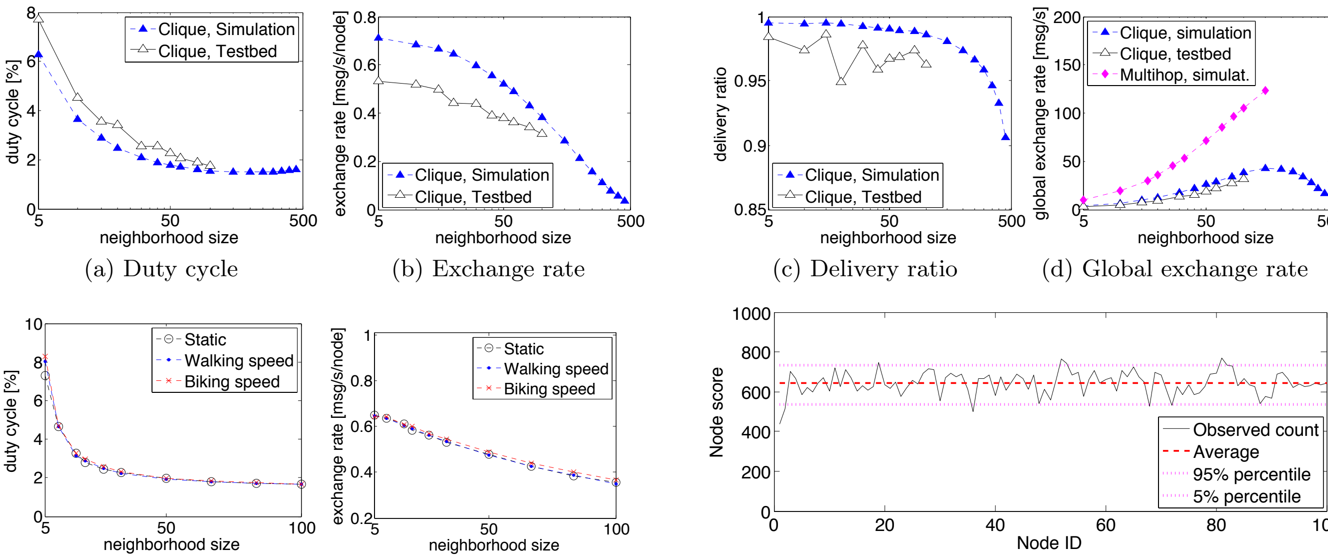
2. SOFA MECHANISM

In this paper we propose *SOFA*, an asynchronous, stateless communication protocol that uses minimal energy and bandwidth to communicate in EWSN. SOFA does not require parameter tuning, and adapts to a wide range of network densities. From tens to hundreds of neighbors.

Extending the mechanism of low power listening protocols, the key idea of SOFA (*Stop On First Ack*) is to choose, opportunistically, the first node that wakes up as *the* receiver. In this way, SOFA avoids the need to discover the nodes' neighborhood and minimizes the inefficient rendezvous phase typical of asynchronous protocols.

Figure 1(a) shows the mechanism of SOFA (that we call *opportunistic anycast*) and compares it to low-power listening unicast. While in unicast the expected rendezvous time is half of the destination wakeup period, in SOFA it depends on the number of neighbors. The more neighbors, the less time the sender will have to waste to rendezvous. Figure 1(b) shows the expected rendezvous time (in logarithmic scale) of unicast, broadcast and SOFA when the wakeup period of the nodes is 1 second. With 100 neighbors, the rendezvous overhead of SOFA is 50 and 100 times lower that unicast and broadcast, respectively. Note that SOFA does not interfere with the operation of other communication primitives. In case the network switches from an extreme condition to a normal one, the protocol stack can switch to the use of standard broadcast and unicast messages.

SOFA's opportunistic anycast has a strong relation with a family of randomized networking algorithms called *Gossip* [1]. Gossip is designed for large-scale distributed system and fits well with EWSN. Gossiping does not aim for traditional end-to-end communication but, instead, disseminates information by forwarding it to a random neighbor (or a subset of neighbors). We argue that, in EWSN, Gossip can be used on top of SOFA as an alternative to standard WSN services based on unicast and broadcast.



(a) Duty cycle (b) Exchange rate (c) Delivery ratio (d) Global exchange rate

(e) Duty cycle (f) Exchange rate (g) Random selection

Figure 2: SOFA's performance in extreme conditions. Note that the plots in the first row are in log scale.

3. EVALUATION

To evaluate the effectiveness of SOFA we ran an extensive set of experiments in our 108-node testbed, whose connectivity, with a transmission power of +10dBm, approaches a *clique*. We investigated the effect of mobility, hidden terminals and high densities using Cooja, the standard simulator for Contiki. We simulated an area of 150x150 meters with nodes moving according to a random waypoint model. With a radio range of 50 m and speeds of 0 m/s (*static*), 1.5 m/s (*walking*) and 7 m/s (*biking*), the resulting *multi-hop* networks have an average diameter of just below 3 hops. In all the experiments, nodes listen to the radio for 10 ms every second and act as senders once every 2 seconds. Figure 2 shows the testbed results together with the simulations. Note that the results from our simulations capture, in a pretty accurate way, the trends observed on the testbed. We make the following observations:

SOFA is resilient to extreme densities: Figures 2(a) and (b) show that with increasing densities (number of transmitters) SOFA manages to reduce its energy consumption (*duty cycle*) while maintaining a good *exchange rate* (packets/node/s). Considering that the periodic listening of nodes accounts for 1% of the duty cycle (lower bound), SOFA's overhead is $\approx$ 1% for neighborhood sizes that range from 30 to 500 nodes. *In traditional asynchronous low-power methods the bandwidth saturates with few tens of nodes* (for the parameter used in our experiments). Thanks to its flexibility to a wide range of densities, SOFA does not require any parameter tuning. Due to its efficient rendezvous, SOFA allows hundreds of nodes to periodically communicate every few seconds. The "clique" curves in Figure 2(d) show the number of packets exchanged per second in the network i.e., the *global exchange rate*. Even after its saturation point ($\approx$ 200 neighbors), SOFA gracefully degrades maintaing a delivery ratio of over 90% (see Figure 2(c)). Note that these are clique scenarios, and hence, larger multi-hop networks will exploit spatial multiplexing (parallel exchanges) and achieve higher global exchange rates. The "multihop" curve in Figure 2(d) illustrates the case.

SOFA is not affected by mobility: Figures 2(e) and 2(f) show that the speed of the nodes does not influence neither the energy consumptions nor the exchange rate. Since SOFA is stateless, asynchronous and distributed, it does not waste energy to maintain information about its neighbors.

SOFA supports Gossip: to converge fast, Gossip nodes need to reliably exchange their information with a random sample of their neighborhood. To support Gossip, SOFA (i) provides a random sampling of the neighbors and (ii) reliably exchanges data messages. Figure 2(g), showing the number of times each node was selected (its *score*), proves that SOFA's opportunistic anycast approximates a random sample of the neighborhood. It is important to remark that this evaluation was performed on a static testbed. Mobility would further randomize the selection of neighbors and facilitate the dissemination of data, which drastically reduces the convergence time of Gossip [5].

4. REFERENCES

[1] S. Boyd and A. Ghosh. Gossip algorithms: Design, analysis and applications. In *INFOCOM '05*, pages 1653–1664, 2005.

[2] M. Buettner, G. Yee, and E. Anderson. X-MAC: a short preamble MAC protocol for duty-cycled wireless sensor networks. In *SenSys '06*, pages 307–320, 2006.

[3] A. El-Hoiydi. WiseMAC: an ultra low power MAC protocol for the downlink of infrastructure wireless sensor networks. In *ISCC '04*, pages 244–251, 2004.

[4] F. Ferrari, M. Zimmerling, L. Mottola, and L. Thiele. The low-power wireless bus. In *SenSys '12*, pages 1–14, 2012.

[5] A. D. Sarwate and A. G. Dimakis. The Impact of Mobility on Gossip Algorithms. *IEEE Transactions on Information Theory*, 58(3):1731–1742, Mar. 2012.

[6] Y. Sun and O. Gurewitz. RI-MAC: a receiver-initiated asynchronous duty cycle MAC protocol for dynamic traffic loads in wireless sensor networks. In *SenSys '08*, pages 1–14, 2008.