Poster Abstract: NoSE: Efficient Initialization of Wireless Sensor Networks

Andreas Meier, Mischa Weise, Jan Beutel and Lothar Thiele
Computer Engineering and Networks Lab, ETH Zurich, 8092 Zurich, Switzerland
a.meier@tik.ee.ethz.ch

ABSTRACT

There are numerous possibilities to assemble a very resource-efficient and power-aware distributed sensor network tailored to a specific application. However, the task of *initializing* the network has not yet attracted much attention. This paper presents the NoSE (Neighbor Search and link Estimation) initialization scheme. NoSE provides an exhaustive neighbor search including a thorough link assessment, leveraging both high reactivity and greatly minimized energy consumption. Based on the information obtained in the initial link assessment phase, a routing protocol can subsequently set up and use an optimized network topology.

Categories and Subject Descriptors: C.2.2 [Network Architecture and Design]: Wireless Sensor Network

General Terms: Algorithms, Design, Performance

Keywords: Wireless Sensor Networks, Initialization, Low power, Responsiveness, Neighbor search, Link estimation

1. INTRODUCTION

Typical WSN applications are optimized for the operational phase of the network. The initialization is usually greatly neglected, either trading off the *responsiveness* or the *energy consumption*. The main issue is, that the deployment of the nodes, i.e. the phase where nodes are being installed takes days rather than hours, sometimes even weeks. So the first nodes that are being installed and powered on are likely to be in solitude for a long time. If these nodes are intensively listening for ongoing communication or actively broadcasting announcements, a lot of energy is wasted, long before the system could possibly start becoming operational! More sophisticated protocols try to switch to energy saving modes after a certain period, reducing the listening and beaconing frequency [1]. This results in a reduced responsiveness and considerably delays the node's joining to the network. This potential delay is far reaching: if a node is not reporting, it is unknown, whether this particular node is not yet connected, has triggered an internal error, was deployed out of communication range or simply has run out of power.

The low-power radios being used in a multi-hop deployment result in a large fraction of poorly connected nodes. This makes it essential that the communication links are carefully selected in order to not waste energy doing unnecessary retries or when changing the topology. Topology changes are especially common during the start up of a network as link assessment is not yet based on significant statistical data. For instance, for the TinyOS-2.x Collection Tree Protocol (CTP) low-power implementation we have experienced about an hour settling time and many resulting parent switches for establishing a stable topology (Table 1). A similar characteristic is exhibited by the very energy efficient data gathering scheme Dozer [1], which is also tuned for an optimized operational phase, but in turn neglecting much of the initialization. There are customized schemes for initializing the network; in particular the most prominent solution of the Birthday protocol [3] that performs an exhaustive yet not time-bound neighbor search without link assessment.

SenSys'08, November 5–7, 2008, Raleigh, North Carolina, USA.

2. NoSE INITIALIZATION SCHEME

Filling the gap for a *time-bound* initialization scheme that provides an exhaustive neighbor search, including a thorough link assessment, motivated the designing of NoSE. A comparison between NoSE and the previously discussed protocols is provided in Table 1. An essential design criteria is the integration into existing protocol stacks, which resulted in building NoSE on top of the most widely used low power listening scheme [2] as used in B-MAC, WiseMAC, X-MAC, SpeckMAC and many more.

The NoSE initialization scheme is split up in three phases, as indicated in Figure 1. After powering on, the node enters the very energy efficient deep sleep *deployment phase*, only

Protocol	NoSE	Dozer [1]	B-day [3]	T2 CTP
Deterministic Time	✓	✗	✗	✗
Link Assessment	✓	✗	✗	✗
Stabilization [min]	3	20	✗	60
Duty Cycle[a]	0.3%	1.1%	1.0%	1.5%
Mean Current [mA]	0.28	–	0.41	0.67

[a]Newly started node during deployment phase (first six hours) if neighbors are not yet present.

Table 1: Performance of different protocols during initialization, measured on a 25 node (Tmote Sky) network.

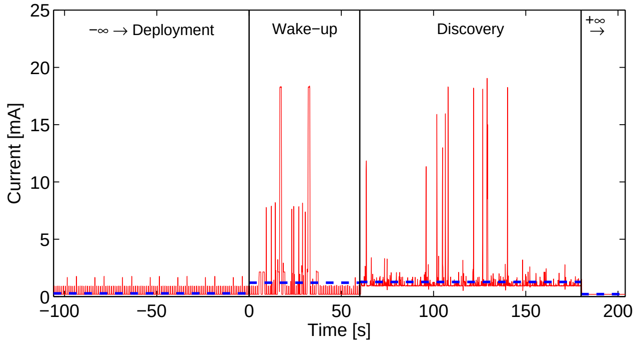

Figure 1: NoSE's power and responsiveness analysis.

waking up every ∼2 s waiting for a wake-up call that is triggered manually as soon as all nodes are deployed. The deep sleep phase is introduced in order to save energy after the node is initially turned on; in particular not wasting great amounts of energy for exploring the neighborhood as long as not all neighboring nodes are not yet deployed. The wake-up call is then flooded in the network during the *wake-up phase*, making all nodes aware of the upcoming loosely synchronized *discovery phase*. During the discovery, all nodes send a well-defined number of broadcast messages N at random time, making it beneficial to reduce the MAC's polling interval T_P. This saves a lot of energy on the order of $1/T_P$ and largely increases the responsiveness due to the temporarily increased channel bandwidth. The discovery phase ends synchronously for all nodes, providing all the essentials (complete neighbor list and corresponding link qualities) for setting up a greatly optimized network topology.

3. EVALUATION

For evaluation we implemented NoSE in TinyOS-2.x on the Tmote Sky platform, and evaluated on a 25 node testbed in an office like scenario. Furthermore we implemented the Birthday protocol [3] for reference purposes.

3.1 NoSE vs. Birthday

NoSE and Birthday both aim at finding all available neighbors. In Table 2 it is shown, how well the two perform this task, by sending 20 discovery broadcasts. The table segments the number of found neighbors according the measured link quality (PRR). Of all the available high quality links (PRR > 0.95), both protocols find almost all links available. The same holds for links with a link quality of 85-95%. However, both protocols also find a substantial amount of links, with a poor link quality. These links should not be included, emphasizing the necessity of a link assessment prior to setting up of the routing tables.

For the Birthday protocol, the end time of the discovery differs for the nodes in the network. Here a node does not know about the state of the network wide discovery, its finishing time and when to start the next step of the initialization, the set-up of the routing tables. NoSE on the other hand features a synchronous, time-bound and deterministic discovery phase, allowing for a smooth transmission to the subsequent routing set-up phase. Furthermore, NoSE runs a duty cycle in the order of 10% during discovery phase, whereas the Birthday protocol runs at a 100% duty cycle.

PRR [%]	> 95	$85 - 95$	$50 - 85$	< 50
#Links	155	45	42	75
NoSE	97.8%	88.8%	80.8%	59.3%
Birthday	97.0%	91.9%	82.5%	70.4%

Table 2: Neighbor discovery in NoSE and Birthday.

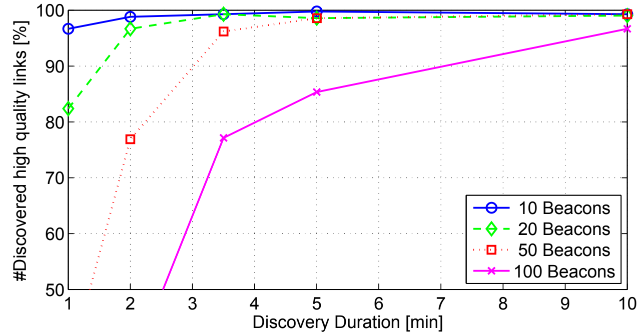

Figure 2: NoSE Discovery: Channel saturation.

3.2 Discovery Duration

NoSE link assessment is based on the knowledge that all nodes in the network send N discovery messages, i.e., the fraction of the N messages received from a neighbor indicates the link quality. This assumes that messages are lost due to bad link quality and not due to collisions. For this exact purpose, NoSE reduces temporarily the radio's polling interval T_P, which increases the network's bandwidth.

The influence of collisions on the link estimation is analyzed in Figure 2 with a maximum node density of 12 neighbors and a polling interval $T_P = 0.1$ s. The plot shows, for how many of the high-quality links at least 90% of the N messages have been received. For instance it shows that for 50 messages, a discovery time of at least 5 minutes should be chosen. As a rule of thumb, for every 10 messages being sent, the discovery should last an additional minute. This translates to a 20% channel utilization, which should not be exceeded for ensuring a well-assessed link estimation. The discovery phase can therefore be reduced by shortening the polling interval T_P. However, a reduced discovery phase also shortens the channel assessment time, resulting in a fragile estimation susceptible to short-term link fluctuations.

4. CONCLUSION

The combined, time-bound initialization and link estimation scheme proposed by NoSE offers a flexible and adaptable way to optimize power consumption and responsiveness for many WSN applications alike. Especially the capability to wake up from an ultra-low power deployment phase and transit to a high-performance protocol scheme for operation is a novel and promising approach. Our implementation and performance assessment of the NoSE implementation underpins its versatility in practice.

5. REFERENCES

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