DESYDE: Decentralized (De)synchronization in Wireless Sensor Networks

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Abstract

In the full version of this paper (Mihaylov et al., 2011) we propose DESYDE: a decentralized approach for coordinating the radio activity of wireless sensor nodes. Inspired by the *win-stay lose-shift* strategy from game theory, our approach allows individual nodes to schedule their radio transmission, reception and sleeping periods without any form of explicit coordination. We implement DESYDE in the OMNeT++ sensor network simulator and compare its performance to two state-of-the-art scheduling protocols, namely S-MAC and D-MAC. We show that our approach adapts the wake-up cycle of each node to its traffic load and significantly reduces end-to-end communication delays.

1. Introduction

Wireless Sensor Networks (WSNs) are a recent class of networks able to monitor our daily environment with a high spatiotemporal accuracy (Ilyas & Mahgoub, 2005). WSNs are composed of small sensing devices, also known as wireless sensor nodes, endowed with sensing, processing and wireless communication capabilities. The limited resources of the sensor nodes make the design of a WSN application challenging. Application requirements, in terms of latency, data throughput, or lifetime, often conflict with the network capacity and energy resources. The standard approach for addressing these tradeoffs is to rely on *wake-up scheduling* (Ilyas & Mahgoub, 2005), which consists in alternating the active and sleep states of sensor nodes. The fraction of time in which the node is in the active mode is referred to as *duty cycle*. The period of this cycle is called *frame*, which can be further divided into a number of *time slots*.

Wake-up scheduling offers an efficient way to significantly improve the lifetime of a WSN application, and is well illustrated by S-MAC, a standard synchronized medium access control (MAC) protocol for WSN (Ye et al., 2004). In S-MAC, the duty-cycle is fixed by the user, and all sensor nodes synchronize in such a way that their active periods take place at the same time. This synchronized active period enables neighboring nodes to communicate with one another.

In the full version of this paper (Mihaylov et al., 2011) we demonstrate how the performance (in terms of lifetime and data latency) of a WSN network can be further improved, if nodes not only synchronize, but also *desynchronize* with one another. More precisely, the duty cycles of nodes that need to communicate with one another are synchronized to improve message throughput. We say that those nodes belong to one *coalition*. At the same time, the schedules of groups of nodes which do not need to communicate are desynchronized in order to avoid radio interferences and packet losses. We refer to this type of coordination for short as *(de)synchronization*.

Our approach allows sensor nodes to coordinate their activities in a decentralized manner, by relying on the win-stay lose-shift (WSLS) strategy drawn from game

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theory (Posch, 1999). We call the approach DESYDE, which stands for DEcentralized SYnchronization and DEsynchronization.

2. DESYDE

In DESYDE, the coordination is achieved by rewarding successful interactions (e.g., acknowledged transmission) and penalizing the ones with a negative outcome (e.g., message loss or overhearing). This behavior drives the sensor nodes to repeat actions that result in positive feedback more often and to decrease the probability of unsuccessful interactions. Nodes that tend to select the same successful action naturally form a coalition. The main benefit of the proposed approach is that global (de)synchronization emerges from simple and local interactions without the need of central mediator or any form of explicit coordination.

We implement DESYDE in the OMNeT++ simulator (www.omnetpp.org), and study its performance in terms of lifetime and data latency for a data collection task, in which all nodes periodically report their data to a base station. We consider three different wireless sensor network topologies, namely line, grid, and random, and assume that the data are relayed from the nodes to the base station by means of a routing tree. We compare DESYDE to S-MAC (Ye et al., 2004) and D-MAC (Lu et al., 2004), two state-of-the-art coordination mechanisms for WSNs, and show that nodes form coalitions which improve data communication and reduce packet collisions. This enables a quicker delivery of the data packets to the base station, allowing shorter active periods. Comparing to the aforementioned protocols, we measured up to 50% lower energy consumption and a 10-fold reduction in latency on 50-node random topologies. On the grid topologies DESYDE achieves the low latency of S-MAC with 5 times lower duty cycle.

These improvements are obtained thanks to the (de)synchronization of the sensor nodes' schedules. We provide in Figure 1 an example of the schedules after applying DESYDE on a simple 2 by 2 grid topology. In this example, the frame contains 10 slots, and the four schedules reported are those of the four nodes in the grid, arranged in the same topological order. At slot 2, the upper left node transmits when the lower left node receives, while the right nodes are synchronized for communication at slot 5. The lower left node sends its data to the base station at slot 7 and forwards that of the upper left node at slot 9. The lower right node does the same at slots 4 and 6, respectively. Thus, we observe the same coalitions as in our schematic model in Figure 1 (left).

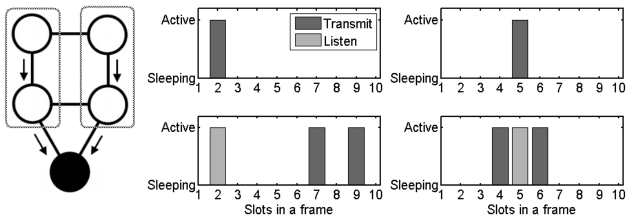

Figure 1. DESYDE

3. Conclusion

State-of-the-art synchronized protocols only perform well in simple networks, such as line topologies. As the network complexity grows, these protocols result in high latency and energy costs, due to the increased number of packet collisions and packet retransmissions. By mitigating these effects, DESYDE was able in all our experiments to compete with standard approaches, and exhibited significant gains in latency and energy especially for larger networks.

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