Energy savings in wireless ad hoc sensor networks as a result of network synchronisation

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Abstract. In this paper, we briefly examine network synchronisation as proposed for the SECOAS project with the purpose of oceanographic monitoring using a collegiate-managed autonomous network of energy-conscious wireless sensors. We discuss the specific characteristics of a novel protocol SSSNP (Self-Synchronised Sensor Network Protocol) that provides energy savings and facilitates collegiate interaction. We argue that the stateless self-synchronisation techniques and the adaptive control of interference used in SSSNP contribute to substantial energy savings in wireless sensor networks.

1 Introduction

Wireless ad hoc sensor networks are designed to satisfy the demands of the spatial-temporal representation of the environment, as explained in [1] and [2]. To achieve this, the network of sensors must be able to operate in hazardous terrain with limited physical access after deployment. Sensor networks must be able to tolerate variations in environmental conditions and network topology in order to maintain data transport, and reconfiguring after individual or collective failures. Moreover, mechanisms for energy savings at predefined intervals, without serious impact on transport capacity and overhead, are required. Environmental monitoring takes place over long periods when unpredictable and exceptional phenomena occur, such as thunderstorms and earthquakes. Because of this and restricted access to the nodes after deployment, a long operational life is crucial. Therefore, sensor networks must demonstrate adaptive and autonomous behaviour to avoid endangering the availability of limited local resources, particularly unnecessary battery drainage, based on interpretation of local knowledge and collegiate node interaction. Data forwarding and collegiate node interaction are certainly the main sources of network activity in ad hoc sensor networks.

Relevant research has shown the use of synchronization for different purposes in wireless networks. In [3], the authors argue that synchronisation can be used for developing a time service for ad hoc sensor networks. In [4], the authors propose using node-to-node synchronised transmissions in order to reduce overhearing and therefore reduce energy expenses. SSSNP (Self-synchronised Sensor Network protocol) is a self-synchronised stateless protocol which makes use of simple vicinity awareness for building structured multi-hop communication. SSSNP has been proposed as part of the SECOAS project, as explained in [2]. We argue that using a self-synchronised protocol for wireless ad hoc communication has distinctive characteristics for energy efficiency for wireless network activity and therefore contributes to extending operational life without detriment to data forwarding and collegiate node interaction.

This paper is organised as follows. Section 2 describes the motivation for energy savings in wireless communication in sensor networks. Relevant research concerning methods of network synchronisation and energy-aware communication protocols for sensor networks is also included in this section. SSSNP and its particular arrangements for facilitating collegiate interaction are briefly described in Section 3. We illustrate our arguments using results from simulation experiments in Section 4. Future work and conclusions are discussed in Section 5.

2 Motivation

Network topology in sensor networks for environmental monitoring changes over time for many reasons and may seriously increase energy drainage. Therefore, communication protocols should flexibly handle those changes with little impact on energy expenditure, as reviewed by Akyildiz *et al* in [5]. Gonzalez *et al* [6] proposed a mechanism for handling communication of short duration in sensor networks, to respond to the problems caused by high mobility and sudden changes in communication conditions. Several energy-aware protocols for sensor networks have been proposed, such as [4], [7], [8], [9] and [10]. Collisions, overhearing, idle listening, and control messages are usually considered as the main direct sources of unproductive transmissions in wireless ad hoc sensor networks. Experiments in [11] indicate that idle listening can represent 50% to 100% of the energy used in typical wireless MAC protocols. SMAC, as proposed by Ye [4], aims to reduce overhearing and idle listening by synchronising node-to-node schedules. In SMAC, Nodes are required to turn the radio interface off and on, based on the duration and timing of the current schedule. In spite of the fact that the results presented indicate a reduction in overhearing and collisions, the use of one-to-one schedules and node-to-node communication reduces the opportunities for scaling which is crucial for the purposes of SECOAS. Additionally, it does not provide direct opportunities for facilitating collegiate node interaction by restricting broadcast transmissions of high significance to the local group. The Stateless operation, self-synchronisation and self-organisation techniques used in SSSNP aim to effectively reduce and prevent direct sources of unproductive transmissions and consequently preserve energy for operational life.

3 The Self-Synchronised Sensor Network Protocol (SSSNP)

SSSNP is a stateless self-synchronised protocol for sensor networks. SSSNP synchronises network activity in operational cycles according to relative proximity to the base station in the network. By doing this, nodes perceive nearby transmissions very close in time to their own. As a consequence of this arrangement, nodes organise themselves to participate in collegiate activities, as well as having simple mechanisms for data forwarding. If the need arises, or if data communication is temporarily impaired, nodes can ineffective transmissions. SSSNP provides three main services to nodes in the sensor network: (i) ARUD (Ad-hoc transmission Resource Unit Distribution) offers collision avoidance and allocation of radio transmission/reception resources; (ii) IE (Inducement engine) offers reliable and anticipated opportunities for transmission in coordination with nearby receivers and transmitters; and (iii) DFE (Data Forwarding Engine) offers robust data forwarding to and from data collectors. ARUD handles radio abstraction methods and provides support for the services provided in (ii), and (iii) with network activity information. IE operates buffers, builds relative mapping of the neighbourhood, manages synchronisation and radio operation, and it provides support for collegiate and data forwarding processes running locally. Finally, DFE efficiently forwards messages across the network taking advantage of the directionality of the synchronous activity in the network.

SSSNP organises the transmission and reception of messages into operating cycles, providing predictability of operation, resilience and simple implementation. Thus, nodes attempt to run on continuous cycles, each with a single opportunity to transmit. Being able to operate inside predictable cycles, the nodes can calculate their acceptance to transmission and reception prospects to manage their internal load. The transmission space in SSSNP is organised in a continuous set of time slots of maximum length *S* each, with M different orthogonal divisions of the physical channel. Spectrum re-usage can be achieved using the set of orthogonal divisions M in different time slots and across the physical terrain. Transmitters individually bind their network activity into continuous operating cycles of length F times S each, thus simplifying their notion of time by avoiding implementation of an absolute time reference. Transmitters aim to identify one time slot *f* for transmission from the F available on any cycle using a particular division *m* from the set M that can be used with minimal interference on their current potential reception area *p*. Fig. 1 illustrates the process in which nodes running SSSNP locally induce others to defer or bring forward their transmissions to achieve synchronisation.

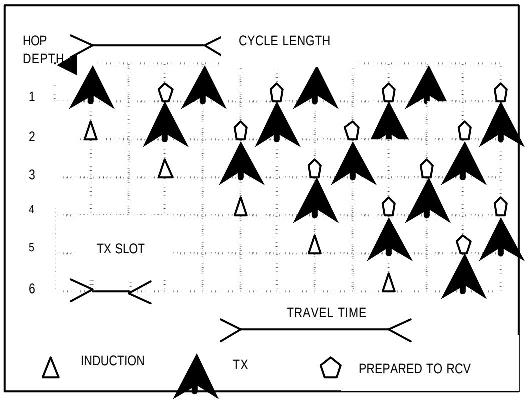

Fig. 1 *Synchronisation process in the Upstream. The induction process produces synchronised hop-based communication. Nodes pay attention to nearby transmission for collegiate interaction and data forwarding*

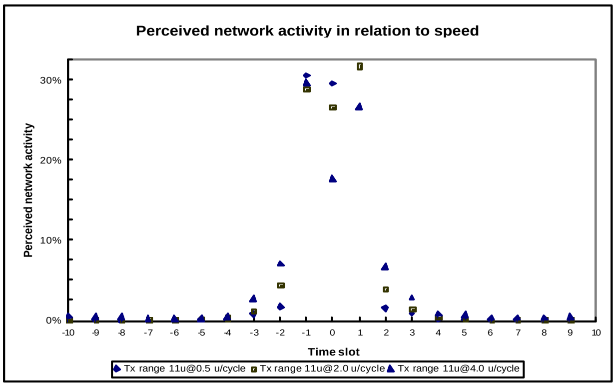

Fig. 2 *Global perceived network activity in a 100 node network using different speed settings. Plots are drawn with respect to the individual opportunity for transmission and for the time slots available*

SSSNP introduces the concept of relative proximity to data collectors using transmission patterns. Nodes can establish relative hop distance difference to the data collectors of nearby transmissions with a high level of probability. The continuous occurrences of nearby transmissions in a particular time slot provide relative information about the presence of other induced nodes. Since the operating cycle repeats itself every F time slots, setting F to small values reduces the opportunity to use relative proximity as a reliable measure; however, it produces valuable estimates for nodes with transmission patterns up to two time slots of distance from their own. The notion of relative proximity is particularly valuable for induced nodes immediately next to the data collector that have lost contact with the transmission pattern. Nodes that have lost contact with the transmission pattern adaptively adjust their operation to the current conditions. Non-induced nodes scan transmissions for F time slots before considering changing to induced operations. By not reacting immediately to the first transmission available, nodes can use the relative proximity information to re-join the network in phase synchronisation to transmissions that provide a convenient hop distance to data collectors according to their updated position, avoiding interference with transmitters in the vicinity.

4 Experiments and results

An agent-based simulator was used to test our proposals; a single experiment was set up and three graphs were produced. One hundred sensor nodes were randomly placed in an area of 70 by 42 units. A unique static data collector was placed in the centre of the area. Nodes followed random trajectories with an indicated maximum relative speed but unable to move outside the virtual limits that the space provided. All nodes and the data collector have the same nominal transmission range, which for practical uses was considered with a circular footprint.. Time slot length, *S*, was set to one epoch and the operating cycle was set 20 time slots. An application scenario of continuous sampling was recreated for producing steady network activity. An additional "virtual" radio receiver was placed on each node for perceiving all potential messages that the node might receive if it had the radio switched on all the time. The first two hundred epochs of each run were considered as a "warm-up" period during which results for perception were not measured. For the next five hundred epochs, data were obtained and plotted for all the nodes in the network. Interference information was gathered for the full seven hundred epochs. Fig. 4,

Fig. 2 and Fig. 3 show the results. In

Fig. 2, it can be seen that network activity: a) is sharply concentrated in the nearby transmissions very close in time to their own transmission; and b) a reduced number of transmissions originally occurring two hops away can be perceived due to mobility. Fig. 3 shows the accumulated percentage of perceived transmissions if the radio remains switched on for a specific number of time slots and shows that c) having the radio switched on for only three time slots, maximises its listening budget. Fig. 4 plots the presence of interference with respect to transmissions every 10 time slots. It can be seen that d) although during the initial deployment period the interference is slightly higher than during normal operation, e) interference is kept under control at all times.

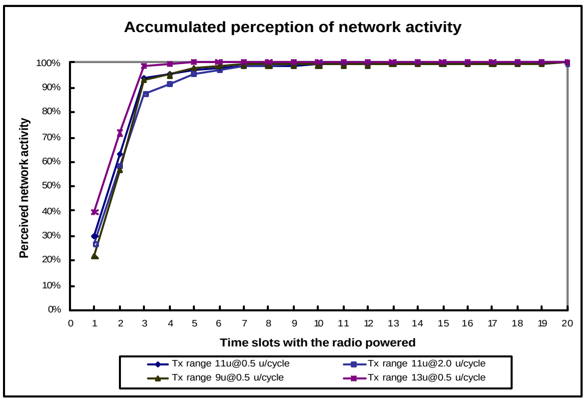

Fig. 3 *Accumulated perception of network activity in a 100 node network. Nodes may avoid unnecesary overhearing by turning the radio off for long periods*

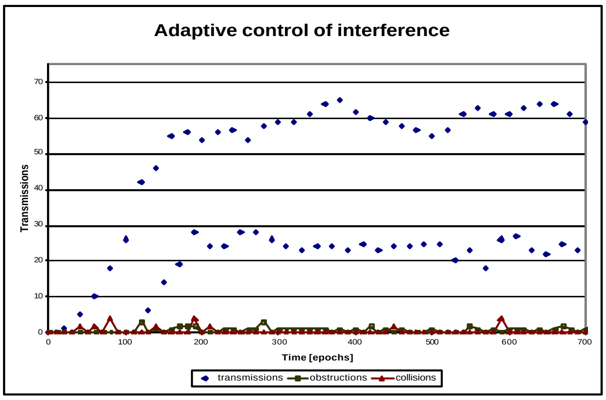

Fig. 4 *Adaptive Control of interference in a 100 node network accumulatively measured in periods of 10 epochs*

5 Conclusions and future work

We have argued that the self-organised synchronisation and adaptive autonomous network services provided by SSSNP produce robust operation to be used in sensor networks for environmental monitoring. Using specific experiments it was shown that SSSNP is able to facilitate collegiate activities as well as providing reliable data forwarding with specific awareness of energy expenditure. Collisions, overhearing, idle listening, and control messages can be reduced accordingly in SSSNP. Points a), b), c), d) and e) in Section 4 illustrate some of the reductions that can be achieved. Amongst the main reasons for achieving these are: The self-organised synchronisation technique, not having control-specific messages, autonomous operation, and the particular organisation of the wireless spectrum. However, although this set of results looks promising, field prototyping is crucial to fulfil our objectives. Further study of different contributors of energy expenditure is required and improvements to the proposals outlined here may follow.

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