Information Managed Wireless Sensor Networks with Energy Aware Nodes

Geoff Merrett, Bashir M. Al-Hashimi, Neil White and Nick Harris

ESD Group, School of Electronics and Computer Science, University of Southampton, UK
{gm04r, bmah, nmw, nrh}@ecs.soton.ac.uk

ABSTRACT

Wireless sensor networks are continuing to receive considerable research interest. The energy constraint inherent in the small battery powered nodes presents a considerable problem, and much effort is being put into reducing the power consumption. In this paper, we introduce IDEALS (Information manageD Energy Aware aLgorithm for Sensor networks), which aims to extend the network lifetime for important messages. This is obtained through the possible loss of low importance messages. IDEALS is fundamentally built upon a concept of message and power priorities, and is particularly relevant for energy harvesting nodes. The results obtained from a developed simulator show that considerable advantages can be obtained from IDEALS.

Keywords: wireless sensor networks, energy-aware, information content, energy harvesting, network lifetime

1 INTRODUCTION

Wireless Sensor Networks (WSNs) are continuing to receive considerable research interest due to the extensive range of applications to which they are suited [1-3]. Typically, a WSN consists of a number of small locally powered sensor nodes that communicate detected events wirelessly through multi-hop routing (neighbouring nodes forward messages to their destinations) [4]. Research across all network layers has focused on overcoming problems associated with the energy constraints inherent in the small, battery powered sensor nodes [5]. Research into algorithm development has largely concentrated on energy-efficient routing [6, 7]. The majority of such algorithms were developed with the aim of finding the route from the source to the destination that consumes the least power. This, however, typically results in a rapid reduction in the network lifetime (the period during which the network is practically useable), and hence current research is beginning to focus on spreading the energy cost evenly over the network to maximise network survivability [8].

It is assumed that in addition to their batteries, the sensor nodes in our WSN harvest energy from sources such as mechanical vibration, wind and the sun [9, 10]. Secondly, the sensor nodes are able to monitor the remaining power available to them. The combination of these two abilities constitutes a node being 'energy aware'. Because the nodes harvest energy, they have cyclic lifetimes whereby they come back to life after depleting their energy reserves. Therefore, it is possible to deviate from the traditional assumption that a WSN has a fixed lifetime, after which nodes dying from depleted batteries cause the network to become useless [8].

Until now, algorithms have not explicitly considered the information content of the message (how important the message is). The nodes in our network are able to identify the information content of an event, and process the message accordingly. With this in mind, we refer to such a network as being 'information managed'. The union of information management and energy aware nodes forms the basis of our approach.

In this paper, we present an Information manageD Energy Aware aLgorithm for Sensor networks (IDEALS). The concept of IDEALS is that a node with a high energy reserve acts for the good of the network by forwarding all messages that come to it, and by generating messages from all locally detected events. However, a node with a near-depleted energy reserve acts selfishly, by only generating or forwarding messages that have a high information content. If a node does not wish to participate in the routing of a message, it appears invisible by not responding to neighbours' requests. By doing this, IDEALS is able to extend the network lifetime for important messages, through the possible loss of low importance messages.

2 INFORMATION MANAGEMENT ALGORITHM

In many WSN algorithms, the decision as to whether or not the neighbouring node has enough power to forward a message forms part of a negotiation process [11]. IDEALS allows each node to decide its individual network involvement independently of its neighbouring nodes, based on its own resources and the information contained in the message.

In a traditional wireless sensor node, events occurring in the surrounding environment are detected by various sensors. This data is passed to the controller for processing, following which it is embedded into a message packet and transmitted wirelessly in accordance with the communications protocol. In addition, sensor nodes perform message routing. Therefore, messages received by a sensor node that are destined for a different node should be retransmitted to neighbouring nodes in accordance with the communications protocol. IDEALS functions alongside this traditional framework. As such, it does not require a specific routing algorithm or communications protocol. For the purposes of simulation, flooding [5] is considered due to the inherent simplicity. The basic concept of flooding is that every node repeats received messages by broadcasting them to its neighbours. In this way, messages should be propagated to every node in the network. Figure 1 shows the block diagram for IDEALS. IDEALS is fundamentally built upon a concept of power and message priorities.

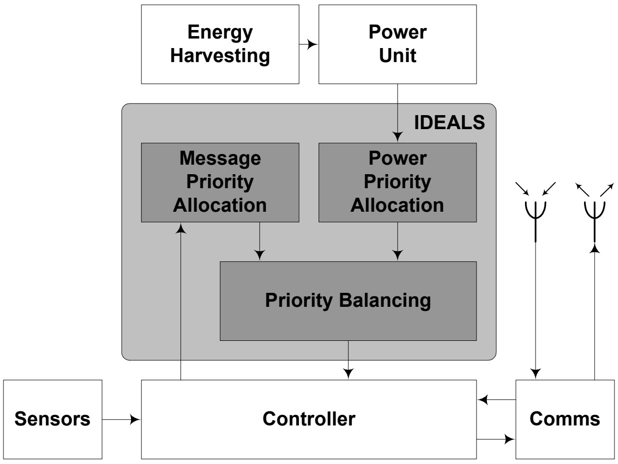

Figure 1: The IDEALS system diagram

As shown in Figure 1, the sensor passes detected events to the controller. The controller supplies the detected event to IDEALS, which scrutinises the information content, and assigns a message priority (MP). A message with a high information content (for example a sensor in a car tyre detecting a large drop in pressure) is given message priority 1 (MP1). In contrast, a message with a low information content (for example a routine 'everything is ok' message) is given MP5. Intermediate message priorities MP2–MP4 are allocated for messages whose information content lies between these two extremes. In addition, IDEALS also measures the residual power available to the sensor node, and assigns a power priority (PP). A full battery is allocated power priority 5 (PP5), while a near empty battery receives PP1. Intermediate power priorities PP2–PP4 relate to the power levels which lie between these two extremes. The priority balancing algorithm then decides whether or not the message should be transmitted, by comparing the PP and MP. The message will be sent if PP ≥ MP. Therefore, as the residual power drops, messages will be selectively discarded in order of their information content. The priority allocation and balancing process can be seen in Figure 2. For example, if the battery is full (PP5), messages with any information content (MP1–MP5) will be transmitted. However, if the battery is empty (PP1), only messages with a high information content (MP1) will be transmitted.

IDEALS is also used during the message forwarding process. When sensor node receives a message that requires forwarding, IDEALS makes the same comparison between the MP (embedded in the transmitted message), and the PP. If the node does not have the required resources to forward the message, the message is simply discarded. For routing protocols that require a handshaking process, the MP is embedded in the handshake data. In this way, the receiving node can decide whether or not to respond to the request. If PP < MP, the sensor node will simply not respond to the request, and appear invisible to the requestor node.

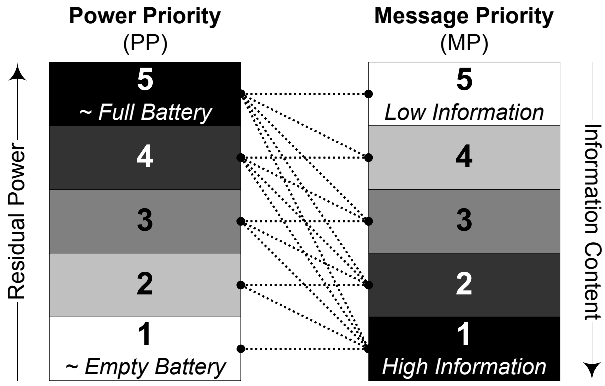

Figure 2: The IDEALS priority balancing mechanism

3 SIMULATION

In order to access the capabilities of IDEALS, WSNsim (wireless sensor network simulator) was developed. WSNsim does not claim to accurately model sensor nodes or transmission channels but, instead, to provide a platform upon which objective observations can be made. WSNsim provides a range of adjustable parameters, which include:

- Number of sensor nodes (randomly scattered)
- Number of events (placed by the user)
- Radio range of sensor nodes
- Energy gain obtained through harvesting
- Power Priority (PP) thresholds

Figure 3 shows a network under simulation in WSNsim. Sensor nodes are represented by black dots, radio ranges by large grey circles, and events by black stars. Energy harvesting is implemented by supplying each node with an energy gain each timestep (an arbitrary period of time). An event is a parameter in the environment that can be measured by a sensor. Each event has a range of dynamic attributes, including position, detectable range (dark grey circles surround the events in Figure 3), and an arbitrary value (for example wavelength or temperature). Through the range of customisable parameters, WSNsim allows the modelling of many different applications.

To measure network performance, WSNsim generates a range of temporal network statistics, including the node power levels and the mean network connectivity. The node power level is the remaining power in each sensor node. Network connectivity is a measure of the ability for a message of priority *x* (MP*x*) to route across the network. If every sensor node in the network can get a message of MP*x* to every other node, the network is said to have a network connectivity for MP*x* of 100%. In contrast, if no messages of MP*x* can be received by any other node, the network is said to have a connectivity for MP*x* of 0%. To provide comparative results, WSNsim allows energy harvesting and IDEALS to be independently toggled on and off.

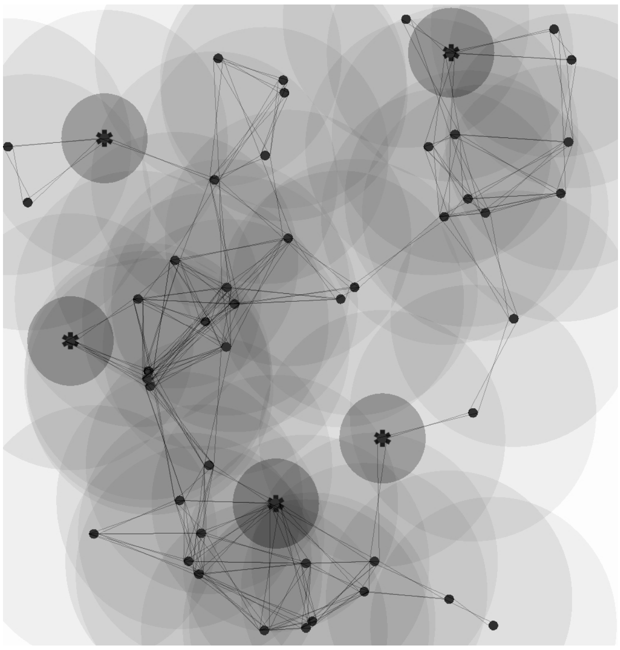

Figure 3: A network under simulation in WSNsim

4 RESULTS

A WSN containing 50 nodes (a realistic network size [2]) was simulated in WSNsim (Figure 3), over four configurations:

a) No Harvesting or IDEALS
b) Harvesting only
c) IDEALS only
d) Harvesting and IDEALS

Five static events were present in the network (one with MP1, one with MP2, etc), with each one detectable by only one sensor node. When energy harvesting was enabled, 0.5% of the full battery capacity was added to each node per timestep.

4.1 Sensor Node Power Levels

Figure 4 shows how the residual power in the node's batteries decreases through time. The values were obtained by taking the average over all the sensor nodes at each timestep. The residual power never reaches 0% in the simulations because the nodes refuse to do anything if their power drops below 5%. This is enforced primarily for the benefit of energy harvesting, to maintain enough of an energy reserve for features such as power management and control.

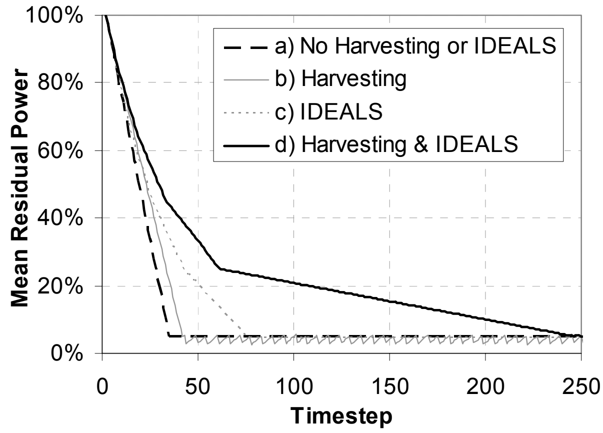

Figure 4: Residual Node Power Levels

As expected, networks that do not feature energy harvesting or IDEALS are the first to deplete their energy reserves (a). If energy harvesting is added (b), the rate of depletion is reduced (as the nodes are receiving a small energy increase every timestep). It can be seen that once the power level of 'b' has dropped below 5%, it then begins to locally oscillate. This is because no messages are sent while the power is less than 5%, and so the node renews its energy. When the power level rises above 5%, a message is sent, and so the power level drops again. If IDEALS is implemented (c), as the power level drops, the rate of depletion decreases in steps at specific stages. These points are predefined as the PP (Power Priority) thresholds in the IDEALS setup. The change occurs as the sensor node's PP changes. By decreasing the PP, the node is dropping messages in order of MP (Message Priority). If energy harvesting is added to IDEALS (d), the effect of IDEALS is emphasised, and the gradients decrease further. Due to the concept of deliberately dropping messages, the power gained by energy harvesting (b) increases the network lifetime considerably more if it is coupled with the IDEALS system (d). To explain this, consider that for each timestep at the beginning of the simulation, five messages are transmitted and a fixed amount of energy harvested. However, at each timestep later in the simulation, message dropping means that only one message is transmitted, while the same amount of energy is harvested.

4.2 Network Connectivity

Figure 5 shows the mean of the network connectivity over the entire simulation, for the five different message priorities (MP1–MP5), and the overall average (ALL).

The network that does not feature harvesting or IDEALS (a) has no priority management, and hence no concept of message priorities. Because of this, the mean network connectivity is the same for all message priorities MP1–MP5. This is also true for network 'b', as it also features no priority management. Energy harvesting (b) provides an increase in the mean network connectivity. This is because the node's energy reserve takes longer to deplete, and even once it has, it intermittently returns to a transmittable state. Adding IDEALS (c) to the basic network provides an increase in network connectivity for important messages, while causing a decrease in network connectivity for low importance messages. Because the network is, on average, less connected for low message priorities, a proportion of the low importance messages will not reach their destination. However, this sacrifice enables a higher network connectivity for important messages. In network 'd', the effect of IDEALS is strengthened by energy harvesting. The increase is not simply the superposition of harvesting (b) and IDEALS (c), as may have been initially expected. This is because of the way that IDEALS emphasises the effect of energy harvesting, as described in section 4.1. As expected, the overall mean network connectivity (shown as 'ALL' in Figure 5) is virtually identical for networks with (c,d) and without (a,b) IDEALS. This is because both networks have the same energy budget.

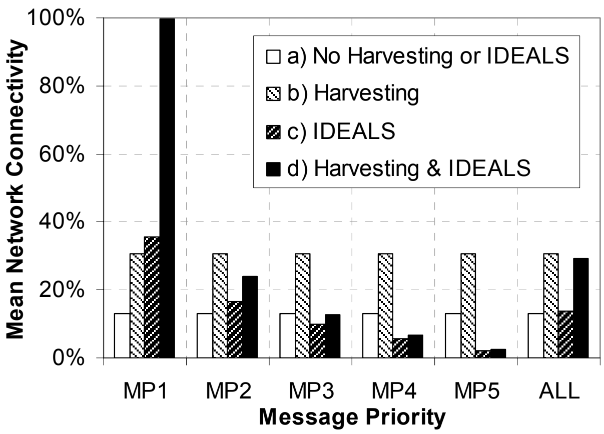

Figure 5: Mean Network Connectivity

The numerical results shown in Figure 5 are only correct for this specific simulation. However, the general trends and observations are common for all simulations. With careful planning, choice of parameters, and priority distribution, it is possible to retain a network connectivity of 100% for the most important messages.

5 CONCLUSIONS AND FUTURE WORK

In this paper, we have introduced IDEALS, an information and power management algorithm that extends the network lifetime for important messages. This is performed through the possible loss of some low importance messages. A simulator (WSNsim) was developed to access the capabilities of IDEALS. The results that we have obtained suggest that an impressive increase in the network lifetime can be obtained for important messages.

For future work, we plan to investigate increasing the intelligence of IDEALS. The information content of the message could be dynamically assessed by the node, as opposed to being preset by the designer. Additionally, the radio range of the sensor node could vary dynamically dependent upon the message priority, so as to reach a cooperative receptor. The node could also dynamically adjust priority levels to automatically optimise the performance for the given environment. For example, where energy harvesting is provided through solar power, at night the network may decide to allow more low priority messages to be transmitted than usual, by 'predicting' an energy increase when the sun rises.

REFERENCES

[1] M. Maroti, et al., "Shooter localization in urban terrain," IEEE Computer, vol. 37, pp. 60-61, 2004.

[2] R. Szewczyk, et al., "Lessons from a Sensor Network Expedition," in Proc. 1st European Workshop Wireless Sensor Networks (EWSN'04), Jan. 2004, pp. 1-16.

[3] K. Martinez, et al., "Glacsweb: a sensor network for hostile environments," in Proc. IEEE Conf. Sensor, Ad Hoc Comm. & Networks, Oct. 2004, pp. 81-87.

[4] J. N. Al-Karaki and A. E. Kamal, "Routing techniques in wireless sensor networks: a survey," IEEE Wireless Comm., vol. 11, pp. 6-28, 2004.

[5] I. F. Akyildiz, et al., "A survey on sensor networks," IEEE Communications Magazine, vol. 40, pp. 102-114, 2002.

[6] C. Intanagonwiwat, et al., "Directed diffusion for wireless sensor networking," IEEE/ACM Trans. on Networking, vol. 11, pp. 2-16, 2003.

[7] Q. Jiang and D. Manivannan, "Routing protocols for sensor networks," in Proc. 1st IEEE Consumer Comm. & Net. Conf. (CCNC), Jan.2004, pp. 93-98.

[8] R. C. Shah and J. M. Rabaey, "Energy aware routing for low energy ad hoc sensor networks," in Proc. IEEE Wireless Comm. and Net. Conf. (WCNC'02), 17-21 March 2002, pp. 350-355 vol.1.

[9] S. Roundy, et al., "Power Sources for Wireless Sensor Networks," in Proc. 1st European Workshop Wireless Sensor Networks, Jan. 2004, pp. 1 - 17.

[10] T. Voigt, et al., "Solar-aware clustering in wireless sensor networks," in Proc. 9th Int. Symp. on Comp. and Comms. (ISCC'04), Jun. 2004, pp. 238-43.

[11] W. R. Heinzelman, et al., "Adaptive protocols for information dissemination in wireless sensor networks," in Proc. 5th Int. Conf. Mobile Comp. and Net., (MobiCom'99), Aug. 1999, pp. 174-185.