Resource aware sensor nodes in wireless sensor networks

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Abstract. Wireless sensor networks are continuing to receive considerable research interest due, in part, to the range of possible applications. One of the greatest challenges facing researchers is in overcoming the limited network lifetime inherent in the small locally powered sensor nodes. In this paper, we propose IDEALS, a system to manage a wireless sensor network using a combination of information management, energy harvesting and energy monitoring, which we label resource awareness. Through this, IDEALS is able to extend the network lifetime for important messages, by controlling the degradation of the network to maximise information throughput.

1. Introduction

Wireless sensor networks (WSNs) have the potential to revolutionise the sensor industry, through the diversity of suitable applications, and the range of advantages obtained using wireless communications. A WSN is typically a collection of locally powered intelligent sensor nodes that are able to communicate detected events with the nodes around them using a wireless channel. In some cases, these sensor nodes may additionally house actuators to actively respond to detected phenomena. Communication between nodes is generally performed using multi-hop routing, whereby neighbouring nodes forward messages to their destinations.

The possible uses of WSNs are virtually endless. Research is currently being driven by environmental monitoring, where sensor nodes are 'scattered' throughout a selected location to monitor a particular range of environmental parameters. One example of this is a project at the University of Southampton placing sensor nodes inside the Briksdalsbreen glacier in Norway in order to gain insight into glacial behaviour, which is of key importance in global warming [1]. Figure 1 shows one of the robust sensor nodes (measuring 12cm in length) that was placed inside the glacier, sensing pressure, temperature, orientation, external conductivity and strain. Additional projects have used environmental WSNs to monitor wildlife patterns [2]. Other uses for WSNs include personal healthcare monitoring, where a wide range of possible implementations can be envisaged. A network of sensors can be implanted or attached to the subject to monitor their medical condition for applications ranging from general patient monitoring [3] to emergency care [4]. The results obtained by this network could then either be analyzed by an external computation unit, or locally acted upon by actuators on the subject. Other uses of WSNs include HVAC (where wireless systems removes the considerable installation cost associated with wiring), structural monitoring [5] and surveillance [6].

WSNs are receiving escalating research interest due to rapid subject growth, research area diversity, and the wide range of applications outlined above. One of the primary concerns is the limited energy budget inherent in the small locally powered sensor nodes [7], and research is ongoing into overcoming associated problems [8]. A number of algorithms have been designed to extend the life of the network [9-11].

We propose an application independent system that extends the lifetime of a WSN through information and energy management – a combination which we label as resource aware. Until now, we believe that this has not been explicitly addressed. The sensor nodes in our network are able to harvest energy from the surrounding environment, for example through sources such as solar power [12, 13], wind power [7] or mechanical vibrations [14]. Because the nodes harvest energy, they have cyclic lifetimes whereby they come back to life after their energy reserves deplete. 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. Theoretically, energy harvesting enables our WSN to operate perpetually, provided that no hardware faults occur, and the resources are managed in a controlled fashion. The sensor nodes in our network are able to monitor the residual energy available to them. Additionally, they are able to identify the information content of a message (how important the message is), and process it accordingly. This combination of energy monitoring and information management constitutes our network being resource aware.

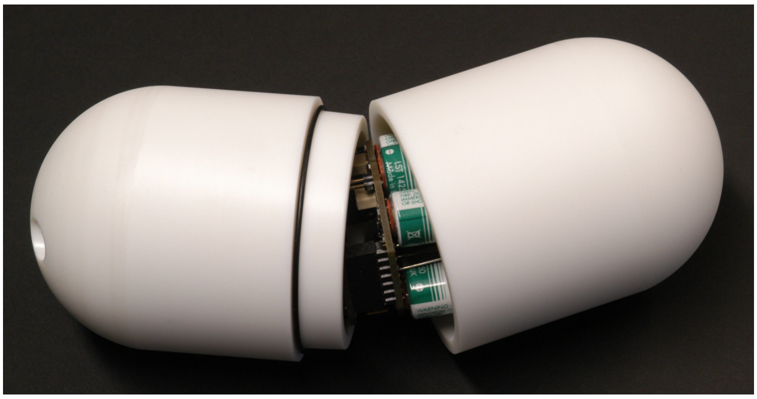

Figure 1. Sensor node from the Glacsweb project [1]

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. Under normal conditions, the network should harvest as much as energy as it depletes, and so IDEALS will appear transparent. However, if an influx of messages occur as a result of a significant event, IDEALS will manage the decline of the network to maintain its usefulness.

2. Resource management

In the majority of energy aware WSN algorithms, the decision as to whether or not a neighbouring node has enough power to forward a message is a distributed process [9]. 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 a traditional framework, and the system diagram can be seen in figure 2.

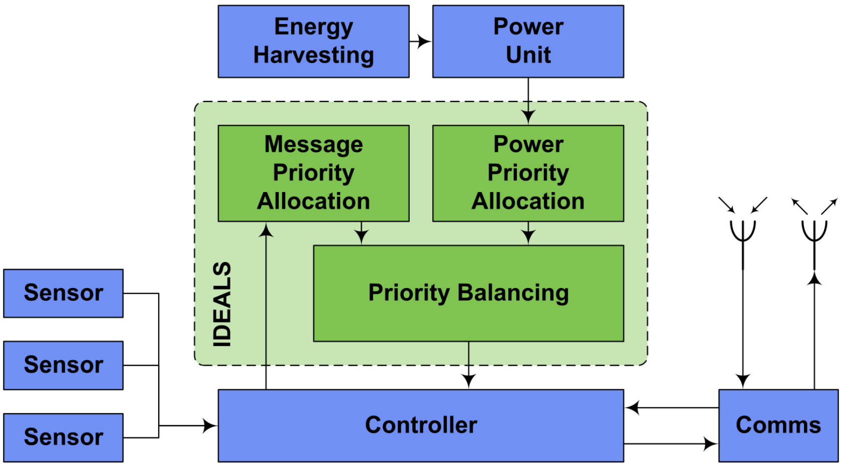

Figure 2. The IDEALS System Diagram

As shown in figure 2, 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 $\geq$ 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 3. 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. It can also be seen in figure 3 that a fraction of the energy is allocated to PP0. This energy is reserved primarily to maintain enough of an energy reserve for features such as power management and control, and no sensing or communications take place.

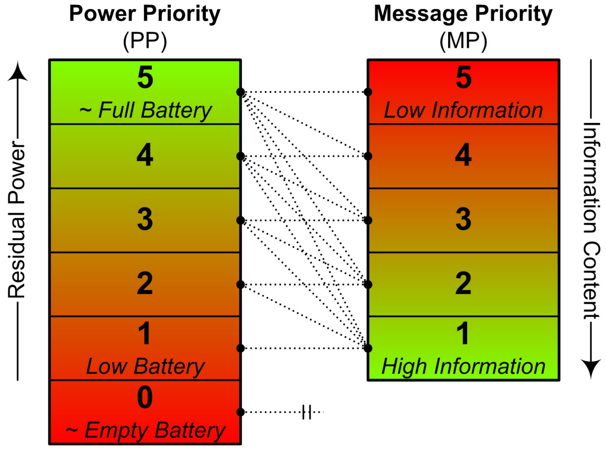

Figure 3. The IDEALS Priority Balancing System. Dotted lines show the message priorities that will be accepted at each power priority.

IDEALS is also used during the message forwarding process. When a 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.

3. Simulation Environment

In order to access the capabilities of IDEALS, WSNsim (wireless sensor network simulator) was developed to provide a virtual environment over which sensor nodes can be scattered. WSNsim provides a platform upon which objective observations can be made, without claiming to accurately model wireless channels or sensor nodes. WSNsim allows the user to place nodes and events throughout the environment, and adjust network parameters including the radio range of sensor nodes, energy harvesting behaviour, and IDEALS system thresholds and parameters.

Through the range of customisable parameters, WSNsim allows the modelling of a variety of different applications. Figure 4 shows a network under simulation in WSNsim. 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, and an arbitrary value (for example wavelength or temperature). Solar power can be modelled simplistically through the implementation of dynamic clouds (not shown in figure 4). At each timestep (an arbitrary period of time), if a sensor node does not lie under a cloud it will gain a preset energy increase.

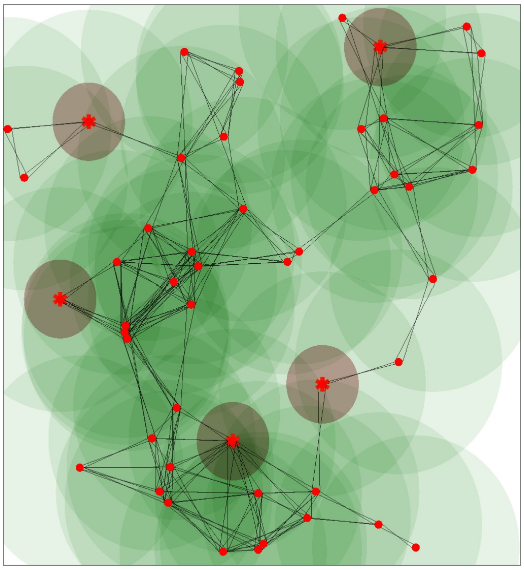

Figure 4. A network under simulation in WSNsim. Sensor nodes are represented by small dots, radio ranges by large semi-transparent circles, and events by stars. Each event has a detectable range denoted by the dark circles surrounding them.

To measure network performance, WSNsim generates a range of network statistics, including the node power levels and the message success. The node power level is the remaining power in each sensor node. Message success is a measure of the percentage of messages that were successfully delivered at each timestep. For example, if there is a 50% message success at a particular timestep, only half of the messages that were sent were successfully received. To provide comparative results, WSNsim allows energy harvesting and IDEALS to be independently toggled on and off.

4. Simulation Results

A WSN containing 50 nodes (a realistic network size [2]) was simulated in WSNsim (Figure 4), over four configurations: 1) No Harvesting or IDEALS, 2) Harvesting only, 3) IDEALS only, and 4) 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, a uniform 0.5% of the full battery capacity was added to every node per timestep. As mentioned earlier, IDEALS is an add-on to a traditional sensor node. As such, it does not require a specific routing algorithm or communications protocol. For the purposes of simulation, flooding [8] 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. The numerical results obtained are only correct for this specific simulation. However, we believe the general trends and observations are common for the majority of applications. With careful planning, choice of parameters, and priority distribution, it is possible to retain a network connectivity of 100% for the most important messages.

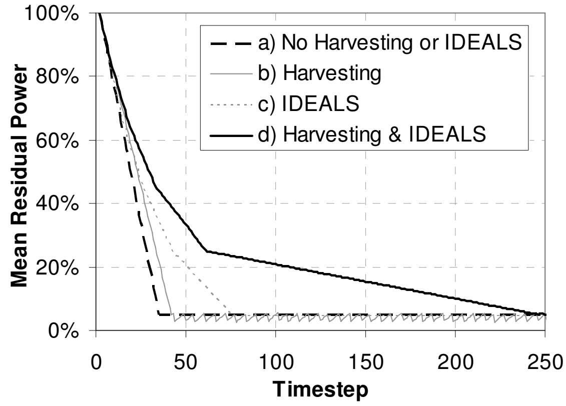

Figure 5. Residual Node Power Levels

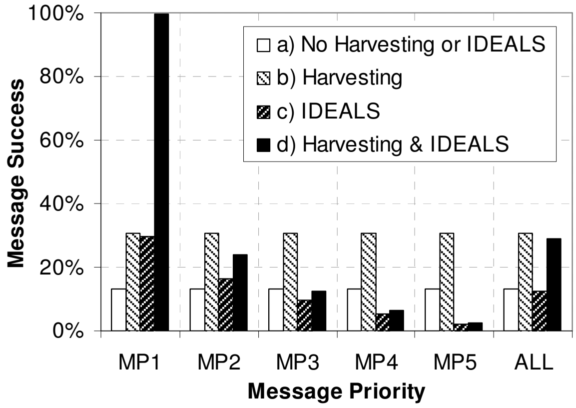

Figure 6. Message Success

4.1. Sensor Node Power Levels

Figure 5 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. 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 as the nodes toggle between PP0 and PP1. If IDEALS is implemented (c), as the power level drops, the rate of depletion decreases in steps at specific thresholds, determined by the PP (Power Priority) thresholds in the IDEALS setup. 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 energy is harvested.

4.2. Message Success

Figure 6 shows the mean message success statistics from the entire simulation, for the five different message priorities (MP1–MP5), and the overall average (ALL). Networks that do not feature IDEALS (a,b) have no priority management, and hence no concept of message priorities. Because of this, the message success is the same for all message priorities MP1–MP5. Energy harvesting (b) provides an increase in the message success, as there is a greater energy budget available, and so the node's energy reserve takes longer to deplete. Adding IDEALS (c) to the basic network provides an increase in message success for important messages, while causing a decrease in network connectivity for low importance messages. As a result of IDEALS, the network is, in general, less connected for low message priorities, and hence a proportion of the low importance messages do not reach their destinations. However, this sacrifice enables a higher message success for important messages. In network 'd', the effect of IDEALS is strengthened by energy harvesting. As expected, the overall mean network connectivity (shown as 'ALL' in figure 6) is virtually identical for networks with (c,d) and without (a,b) IDEALS. This is because both networks have virtually the same energy budget.

5. Conclusions

In this paper we have introduced IDEALS, a system that increases the network lifetime for important messages, at the expense of less important messages. This is achieved through energy monitoring and information management. The simulation results obtained from a developed simulator (WSNsim) shows that a significant extension in the network lifetime can be obtained for important messages.

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