

Using Local and Global Knowledge in Wireless Sensor Networks

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Abstract

To Write...

Chapter 1

Introduction

A wireless sensor network (WSN) consists of a collection of heterogeneous nodes with sensing and, typically, wireless capabilities. These sensing nodes can be extremely complex and powerful devices with the ability to sense multiple phenomena simultaneously, or they can be simple motes that have limited processing power and are tasked with sensing one thing in their environment.

Upon deployment, these nodes use their wireless capabilities to form links with their neighbours, where a neighbour is any node that is within transmission range. The way that nodes discover, and communicate with, their neighbours is defined by their routing protocol. Routing protocols vary based on the purpose of the WSN, the requirements of data transmission as well as the characteristics of the nodes. Communication between nodes is expensive and drains the available power faster than any other action that a node performs. For example, if a WSN is deployed in a building with consistent power available, then the routing protocol does not need to be adapted to ensure the nodes maximise their battery life by transmitting as little as possible. However, not every WSN has unlimited resources at their disposal and these protocols, as well as the underlying structure of the network, are used to ensure the network is able to perform well for as long as possible.

Each WSN is different and each will have different constraints, a WSN that monitors traffic along a busy road may experience memory limitations, whereas a WSN that is deployed in the middle of a desert may experience power issues. Typically, however, all WSNs do the same thing: sense one or more characteristics of their environment and forward that data on to a specified endpoint.

1.1 The Local Knowledge Problem

The majority of WSNs do not have know what data they are sensing, or have any knowledge of their environment. This means that, unless fixed by a routing protocol or human that deployed the network, data is delivered on a chronological basis and is then filtered at the base station, usually manually. Some WSNs store all of the data on the node and users of the network must use a 'pull' model to query for data from nodes, but this requires some technical knowledge and, while it does increase the battery life of the nodes, it is a manual process again.

The environment that a WSN is deployed is usually rich and the data sensed often contains patterns that can be used to improve the performance of the network. For example, if a node knows that it is has only been triggering between the hours of 6pm and 5am for the past few weeks, it can enter a deep sleep outside of those hours or use that time to transmit data it has been storing while it knows it will be inactive. Alternatively, this knowledge can be used to prioritise data throughout the network so that the most important data is received first, instead of the most recent. An example of this could two camera nodes deployed facing the entry and exit of a building, tasked with looking for intruders between 5pm and 8am. If the camera facing the exit is triggered at 5:01pm and the camera on the entrance is triggered at 5:05pm, then the knowledge that the security guard leaves through the exit between 5:01pm and 5:08 pm will allow the entrance camera to prioritise its capture as more important, as it is an irregular occurrence.

This knowledge can be categorised into *local* and *global*. Local knowledge (LK) is the knowledge of an area that has been gained through experience or experimentation and global knowledge (GK) is knowledge that is generally available to everybody. An example of this is someone who has been tasked with deploying a WSN in the Amazon rainforest would use readily available sources, such as the Internet or prior research, to determine the humidity and weather patterns in order to use a node that could withstand such conditions. This would be classed as GK. However, a native to the Amazon may know that three of the locations that the nodes are to be deployed in are flooded for two weeks of the year, rendering their readings useless for that time period and increasing their risk of failure. This is LK, as it cannot be gained without experiencing the flooding in that area, or experimenting with water levels.

We believe that the use of this knowledge can increase the efficiency of the network, as well as prioritise sensed data by its value instead of the time it was recorded. To show this, we have developed a network architecture for WSNs that utilises knowledge from the data it senses, as well as its deployed environment. It is called the Knowledge-based Hierarchical Architecture for

Sensing (K-HAS) and this thesis will show how K-HAS addresses the problem of delivering the most important data first and improving the overall efficiency of the network.

1.2 Motivation

Throughout this thesis, we focus on a scenario motivated by our collaboration with Cardiff University School of Biosciences, who run a research centre in the Malaysian rainforest, in Sabah, known as Danau Girang (DG) . Located on the banks of the Kinabatangan river, DG has been running for more than six years and holds Masters, PhD and Undergraduate students from around the world, studying the ecology and biodiversity of the unique region.

The reason that the rainforest that DG is set in is so unique is that the area was heavily logged until the late 1970s and now serves as a corridor, between large Palm Oil plantations, connecting two separate rainforest lots. The area is now secondary rainforest (rainforest that has grown since being destroyed) and is experiencing a large variety of wildlife using the area as a habitat, or as a path. Some of this wildlife is unique to this area of the world and DG has had sightings of animals that have not been seen in many years.

There is a variety of research projects currently underway in the field centre, looking into fish population, crocodile attacks, hornbill habitats or the movement patterns of small mammals. One project that has been running almost since DG opened, is the *corridor monitoring programme*, a programme that consists of dozens of wildlife cameras deployed in various areas around DG and triggered whenever an animal triggers a break in their infrared (IR) sensor.

The Kinabatangan is a very humid place, with thick forest, making it very difficult to walk through and even more difficult for hardware to survive the conditions. Cameras are placed along the river and up to 1km into the forest, recording triggers onto SD cards. These SD cards are collected and stored at the field centre, where the images are manually collated and processed. The cameras are designed to have a battery life of three months but, due to the humidity, a battery life of 3 weeks is more realistic. In 2010, twenty cameras were deployed and half of them were inspected every two weeks, on a rotating basis. In that time, each cameras can record more than a thousand pictures and the dynamic nature of the rainforest, such as the sun through leaves, falling trees and reflections in the water can cause the camera to trigger when an animal has not walked past; we call these *false triggers*. False triggers can make up to 70

We have used this scenario to test our hypothesis and implement a WSN

that automates the collection, transmission, processing and storage of images, using LK to classify the data and prioritise the flow of information through the network, making more efficient use of the limited power and bandwidth available.

1.3 Research Contributions

1.4 Thesis Structure

The rest of this thesis is structured as follows. Chapter 2 provides some background on wireless sensor networks and the use of knowledge. Chapter 3 explains some technical decisions we made and the findings when running experiments in the Malaysian rainforest. Chapter 4 introduces the K-HAS architecture we have developed and explains the purpose of each tier. Chapter 5 details the ontology we have developed to support K-HAS and shows how current ontologies do not sufficiently cover all of the concepts involved with a *scientific observation*. Chapter 6 shows how we use rules to determine how valuable a piece of sensed data is and to explain how K-HAS is able to use these rules, and human feedback, in order to inform future classifications. Chapter 7 highlights the technical limitations of implementing K-HAS today and shows our simulations of it running as it was designed. Chapter 8 then concludes this thesis and summarises our contributions and findings, as well as highlighting work that could be undertaken to take this project further.

Chapter 2

Background

Using knowledge in a WSN is related to existing research into sensor networks that utilise context-awareness in order to improve their efficiency or adapt their sampling rate.

This chapter is split into the following sections. Section 2.1 outlines the issues surrounding WSN design and deployment. Section 2.3 details relevant existing routing protocols for sensor networks. Section 2.2 shows some examples of existing WSNs that are related to our motivating scenario. Section 2.4 introduces research into local and global knowledge and Section 2.5 shows some related work into WSNs that utilise knowledge or context to prioritise data and/or improve efficiency.

2.1 Wireless Sensor Network Issues

WSNs have been used in a number of domains, for a range of different purposes, from habitat monitoring [18] to military purposes [14] and healthcare [13]. While these applications are vastly different, the technology behind each is very similar. Each requires the use of nodes with sensors attached and each node requires a power source and storage devices.

According to [1], there are eight factors that affect the design of sensor networks, but we focus on a subset that are the most relevant to our research problem. The following points must be considered when designing a WSN:

2.1.1 Fault Tolerance

WSNs typically contain a large number of nodes and each can fail for various reasons, from a lack of power, filling its storage capacity, to factors of the environment causing the hardware to fail. While the sensor nodes that are

used in WSNs typically consist of the same platform, the variation between each deployment means that the device itself must be adapted to its environment, [11] used a custom protective casing for their nodes so that they were able to survive being in the open while ensuring that the transmission range was not affected.

2.1.2 Hardware Constraints

A sensor node typically consists of: a platform that contains the memory and processing power, a sensor (or sensors) and a transceiver that uses a wireless standard, such as Wi-Fi or Zigbee. Cost and size are the most common barriers to entry when designing a WSN. [7] mentions that the expectation of a sensor node is a matchbox-sized form factor. While the research is over ten years old, the original focus on sensor node was *smart dust* [9], small, inexpensive, disposable nodes that can transmit until their power reserve is depleted, [2] mentions that it is a requirement for the nodes to cost less than USD10. In [4], it is noted that, a decade on from the first WSN papers, smart dust has not been realised and the focus has instead been on larger, more powerful nodes that have reduced in cost and grown in power.

The Gartner Hype Cycle for 2013 [?] shows that smart dust is still in early innovation stages and may not be fully commercialised for another ten years. To counter this, research has been focussed on using software solutions to maximise the battery life in these more powerful, more expensive nodes, accompanies with the use of renewable energy sources.

2.1.3 Energy Constraints

The majority of sensor nodes do not have access to a constant power supply and must run on a battery that is, generally, a similar size to the node itself; or smaller. This means that the nodes must be as efficient as possible, knowing when to transmit data and when to sleep. The lifetime of a sensor network is extremely dependent on the battery life of each node and, unlike other mobile devices, they cannot typically be recharged [1]. Much work has been done on power efficient routing protocols, as well as the control of which attached devices are active [16, 6, 15].

The limited resources on the nodes mean that the sensing devices, and transceivers, attached must consume as little power as possible. Some routing protocols implement turning off wireless radios and scheduling a wakeup across the network [19], but the cost of turning off a device can waste just as much energy as leaving it on and sampling at a lower rate; if not more [5].

The use of energy in a node is dependent on how active the sensor(s) are, how much it transmits and receives, the transmission medium used as well as the environment it is in.

2.1.4 Transmission Medium

Common transmission media, such as Wi-Fi, are viable solutions in WSNs when a high data rate is required and power is readily available. However, research has shown that Wi-Fi is extremely power-hungry and [10] shows that Wi-Fi consumes almost 9 times more energy, while transmitting, than other standards, such as Zigbee. Bluetooth is a more power efficient standard that is becoming increasingly popular for sensing devices that are part of the *Quantified Self* movement [17], with wearable devices that report measurements, such as heart rate, steps taken and calories burned. With the advent of the new low-power Bluetooth 4.0, also known as Bluetooth Low Energy (BLE), this standard is supposed to allow months of continuous use on a coin-cell battery [?]. However, the range is limited to 100m and, using the same frequency, as Wi-Fi (2.4GHz) means that it is as susceptible to path loss and reduced transfer rates. [20] shows that a 2.4GHz Wi-Fi antenna is capable of transmitting up to 350m, while a considerably lower frequency of 41MHz was able to achieve links of 10km. The use of 2.4GHz frequencies in wet conditions have been shown to reduce the performance by up to 28%. New low-power, low-frequency standards have emerged in recent years and allow for a considerably longer range and increased battery life, at the cost of transmission speeds. DigiMesh is an example of this and, while it can achieve 250kb/s using 2.4GHz, it has much slower speeds of 125kbps when using the 900MHz spectrum. However, it does offer a range of, up to, 64Km [3].

2.1.5 Environment

The environment that a node is deployed in can have a great impact on almost all aspects of a WSN, such as range and battery life. Harsh environments that are not easily accessible make it difficult to place nodes and protected environments may limit where nodes can be placed. In [12], nodes were deployed within glaciers and had to survive extreme temperatures, lasting without human intervention, for months at a time. [8] attached collars to Zebras that had to withstand high speed movement, dust and high temperatures. The deployment of any node requires extensive research as to the environment that it will be deployed in and adjustments must be made to ensure it is able to survive for extended periods without continued maintenance. Section 2.1.4 also shows that environment does not simply affect the

hardware, but humidity can reduce the transmission range significantly, as well as moisture collecting on wireless antenna can reduce the range for days at a time.

2.2 Routing Protocols

Routing protocols specify how nodes in a WSN are organised, as well as how they transmit data throughout the network. In [?], the more popular routing protocols are surveyed and split into three identified categories: data-centric, hierarchical and location-based. We will use this section to mention existing protocols that are particularly relevant to our work, based on the pre-defined categories.

2.2.1 Data-centric

Sensor Protocols for Information via Negotiation is one of the first data-centric protocols and attempts to address the issue of flooding the network anytime new data is sensed by addressing the data through metadata. SPIN works on three messages passed between nodes:

1. ADV - A message sent by a node when it has sensed new data, advertising what it has recorded.
2. REQ - Sent by nodes that received an ADV to request the data.
3. DATA - Message containing the sensed data.

2.3 Biodiversity Sensor Networks

In this section we will cover existing WSNs that are related to our motivating scenario or, more specifically, biodiversity focussed WSNs that have been deployed to monitor wildlife and/or the environment. WSNs for habitat, and wildlife, monitoring are especially important because these are areas that often need to be untouched by humans. Areas with high human disturbance can influence the abundance of species and some habitats, i.e. underground burrows, may be impossible to monitor without destruction.

One of the most well known WSNs to monitor habitat is the network deployed on Great Duck Island (GDI), an island off the coast of Maine, USA. A network consisting of 32 nodes was deployed to monitor a bird, known as the Leachs Storm Petrel [11]. This network used a clustering approach for groups of nodes to send data to a gateway, which would then route it back

to the base station. The base station, located a few kilometres away on the island, has internet access and uploads the data to allow users to browse and process the data.

A multihop approach was used here as they found that, for sufficient coverage, single hop connectivity would not cover all of the island. Acrylic enclosures were developed to ensure the nodes were weatherproofed for the conditions of the island, while maintaining the functionality of each sensor and not impeding transmission range. While the nodes, their casing and their sensors have been designed specifically for the deployment on GDI, the success of the network, running for 123 days in the early stages of WSN research [?], shows that this approach can be used elsewhere with similar effects; allowing hard to monitor and/or inaccessible areas to be continuously monitored.

On a smaller scale, INternet-Sensor InteGration for HabitaT monitoring is a single-hop WSN that allows remote access for data and reconfiguring of nodes [?]. While this network does use commercial hardware, their findings do show that their nodes could survive for 160 days on a single battery, supporting their claim that a single hop network allows for a longer network lifetime.

The key feature of this network is the ability for humans to remotely set reporting thresholds for sensor nodes. This means a user can prolong the lifetime of nodes by limiting the threshold they report on, as well as the fact that these thresholds are a way for users to add knowledge, albeit primitive, into a network.

While there is research on cameras used to monitor animals [?, ?], these networks are generally cameras deployed with their memory cards manually retrieved and processed. In recent years, however, the use of wireless technologies and image-based WSNs has increased, [?] uses wireless cameras to monitor the movement of animals between roads. Using commercial hardware and controlled sleep scheduling, this solution employs the use of nodes to detect movement and wake up more power-hungry camera nodes. While the nodes are wireless, the distance of the network from civilisation means that the data does still need to be collected manually and uploaded to a computer.

Due to the advent of smartphones and tablets, as well as the improvements in 3G technology, projects taking advantage of more modern technologies have grown in popularity. Using 3G enabled cameras, [?] have deployed a number of devices in locations all over the world, such as: Kenya, Indonesia and the USA. The images captured are transmitted to a server and a website allows the general public to not only see the images in near real-time, but to classify the images as well. This crowdsourcing of collective knowledge lets

people, that may not have domain knowledge, vote on an image and those votes are used to make classification easier.

Over the past fifteen years, WSNs have grown from a concept to a real solution for monitoring the habitats, movements and eating habits of wildlife all over the world. Whether it is using GPS collars to monitor the movement of cattle [8], monitoring animal habitats on a remote island or using cameras to capture the animals themselves, the popularity of these networks has grown considerably and advances in technology have allowed these networks to be deployed in places that humans cannot.

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