INTRODUCTION TO WIRELESS SENSOR NETWORKS

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To my parents, Radmila and Alexey, who ignited my love for science and computers.

HOW TO USE THIS BOOK

Let us begin by exploring how to use this book and what tools and prior knowledge you will need to learn about wireless sensor networks. The following sections discuss the tools, software, and hardware that are needed as well as where to find them. Additionally, your needed level of programming experience is discussed. If you do not yet have programming experience, resources to obtain it are also offered. Some of the resources are listed here in this book but many more are also available online at the official book website:

comnets.uni-bremen.de/wsn-book/

WHO IS THIS BOOK FOR?

This book assumes that you have more interest in wireless sensor networks (WSNs) than simply buying a ready solution and installing it. Thus, the book is perfect for wireless sensor networks beginners interested in how WSNs work, how to implement them, and how to do research in WSNs. It is also well suited for students both at the undergraduate and graduate levels, programming experts entering the topic of WSNs, as well as hobbyists interested in building their own WSNs.

HOW TO READ THIS BOOK?

Reading this book from the beginning to the end is the best choice. Each chapter starts with an overview of what you will learn and ends with a Summary and

Further Reading section. Chapters 3 to 10 also include Exercises so you can test your knowledge. If you think a chapter is too easy for you, skip directly to the Summary and Exercises to ensure you have not missed something. If a chapter is too hard, read it carefully, making sure you did not miss anything from previous chapters then take all the chapter's exercises to test yourself.

At the end of each chapter, the Further Reading section lists the most foundational and influential resources. These resources are highly recommended to the interested reader who would like to deepen his or her knowledge in specific areas of WSNs. However, they are not essential for understanding the chapters themselves.

WHAT DO YOU NEED TO WORK WITH THIS BOOK?

Obviously, you need the book itself. The book does not assume that you have any specialized experience with wireless sensor networks, but it does assume that you have some programming experience and basic hardware knowledge. Furthermore, it is highly advised to buy some sensor hardware, as discussed below. Apart from the hardware, you do not need any further financial investments as all recommended software tools are either open source or free for use.

Experience or knowledge in computer networking (e.g., TCP/IP, ISO model) is useful, but not necessary. Experience with wireless networks and their challenges are even more useful, but also not necessary. This book will teach you everything you need to know about wireless communications for sensor networks. At the same time, even if you are an expert of computer or wireless communications, you need to be aware of the fact that sensor networking is quite different than these.

PROGRAMMING PREREQUISITES

To benefit from this book, you need to be able to program in ANSI C (not C++). If you cannot do so, but you can program in another language, such as C++, Java, Python, or Perl, you will not find it difficult to learn ANSI C. If you have never programmed before, you should invest more time in learning C first and then return to this book.

There are many ways to learn or refresh your knowledge of C. There are online tutorials, books, and many mailing lists where you can find customized help. The best books to learn C are *Systems Programming with UNIX and C*, by Adam Hoover and *The C Programming Language*, by Brian Kernighan and Dennis Ritchie. Another good option to learn C is to take an online course.

The most important concepts you need from C are pointers and static memory management. This might sound like a step back into the middle ages if you are used to modern concepts such as garbage collectors and dynamic memory management. However, sensor nodes are too memory restricted to provide these functions so you need to allocate the memory often statically and to manage it manually. For this, you need to understand pointers. To find out whether you have sufficient C knowledge, please take the C quiz on the book's website.

SOFTWARE TOOLS AND THE CONTIKI OPERATING SYSTEM

All of the examples in this book and on the corresponding website are written in the Contiki operating system for wireless sensor networks. Contiki is open source and free for use both for non-commercial and commercial solutions. It is well documented and has an extensive community supporting it. For all of these reasons, it is ideal to learn wireless sensor networks, but also offers the possibility to directly use the developed solutions in any environment.

This book's website also provides tutorials to start working with Contiki.

SENSOR NODE HARDWARE

I strongly advise you to buy some sensor node hardware, at least two or three sensor nodes. Buying a single sensor node is not an option; it is like buying a single walkie-talkie. With two, you can let them talk to each other. With three or more, you can even build some interesting applications. If possible, try to get five nodes.

The Contiki website maintains an overview of supported hardware at their webpage: http://contiki-os.org/hardware.html.

Whether a specific platform is supported or not depends on the micro-controller and the radio used (see Chapter 2). A good option is the Z1 platform from Zolertia: http://zolertia.io/z1.

Z1 is popular in academia and the industry, and is fully supported by Contiki and its simulator Cooja. You can check this book's website to see whether this recommendation has changed, which other sensor nodes are supported, and where you can buy them.

Of course, sometimes it is not possible to buy sensor nodes. In this case, you have several options and this book will still be quite useful to you.

- Borrow from the local university. Almost every university in the world, which has an electrical engineering or computer science department, will also have a research group working in wireless sensor networks. You can typically find it in the computer networking or pervasive computing research areas. Thus you can ask the researchers whether you can borrow them for some time.
- Shared testbeds. The favorite testing tool of all WSN researchers is the testbed. A testbed is nothing more than sensor nodes, usually installed in a university building with cables connecting them to a central server and providing them with power. Shared testbeds also provide a web interface to program individual or all sensor nodes and to download experimental data later. An example of such a testbed is INDRYIA in Singapore.[1] If you really cannot find sensor nodes to work with, then a testbed is an option for some more advanced exercises to experience the hands-on feeling and properties of the real-world environment. However, a testbed remains a virtual environment, where you cannot see your

[1] indriya.comp.nus.edu.sg/

application running in real time. Furthermore, it is not trivial to prepare such experiments.

- Use a simulator. Contiki has its own simulator called Cooja. While this is a possibility, I do not recommend it because it will not offer you the experience and satisfaction of having something real in your hands. It is a little bit like learning a new language and being forbidden to speak it. However, Cooja makes it possible to use exactly the same programming code as for Contiki itself and is a good companion while debugging and experimenting.

HOW TO USE THIS BOOK: SUMMARY

You need programming experience in *ANSI C*, especially in concepts of pointers and static memory allocation. Before you start reading this book, you should complete the online quiz and consult the online references.

In terms of *software tools*, you need the Contiki operating system and its tools. You are also urged to look into the tutorials and installation guides, which are available online at this book's website.

In terms of *hardware*, you need at least two or three sensor nodes, although five is best. I recommend Z1 from Zolertia but others are listed on the book's website.

All necessary tools, tutorials and examples from this book along with updated information on supported hardware platforms are available on the book's official website:

comnets.uni-bremen.de/wsn-book/

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WHAT ARE WIRELESS SENSOR NETWORKS?

This chapter introduces wireless sensor networks, what are they as well as what types and applications exist. If you have previously worked with wireless sensor networks and know about their possible application areas, you may want to skip this chapter.

1.1 WIRELESS SENSOR NETWORKS

Wireless sensor network (WSN) is a collective term to specify a rather independent set of tiny computers with the main target of sensing some physical property of their environment such as vibration, humidity, or temperature. They consist of a few to thousands of *sensor nodes*, often also referred to as nodes or sensors, which are connected to each other via wireless communications. Typically, there is also at least one special node, called the *sink* or the *base station*, which connects the sensor network to the outside world. Figure 1.1 provides a general example of a sensor network.

sensor nodes

sink

base station

There are several assumptions or general properties of WSNs, which make them different from other types of wireless networks.

The resources of individual sensor nodes are highly limited. In order to cover large areas for monitoring, the individual sensor nodes need to be cheap. In order to be cheap, their components need to be cheap. Thus, the absolute minimum is installed and used on sensor nodes so their hardware resembles more of a PC from

Introduction To Wireless Sensor Networks, First Edition. Anna Förster.

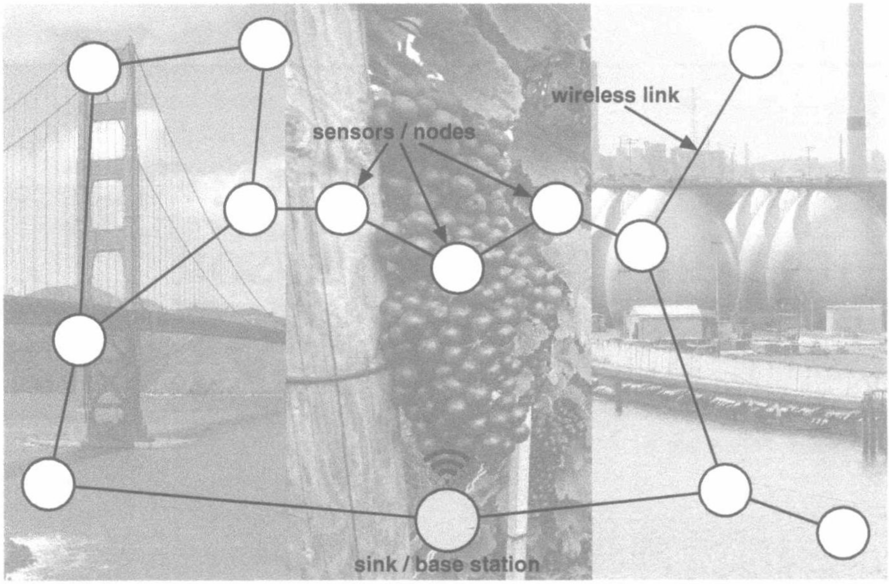

FIGURE 1.1 A typical sensor network with several sensor nodes and one base station. The sensors are connected to each other via wireless links, whereas the base station is typically more powerful and connected to the outside world. The application areas and environments are endless!

the 1980s than a modern device. All the properties and limitations of sensor networks come from this minimal hardware design. For example, this is the reason why not each of the sensor nodes can be equipped with a GPS receiver and a GPRS antenna for communication, but instead only one node can usually afford it (the sink/base station).

The wireless links are spontaneous and not planned. Different from other wireless networks, such as Wi-Fi hotspots, WSNs are not carefully planned to perfectly communicate and enable specific service quality levels. Instead, the assumption is that each of them tries to detect its brothers and sisters, and to exchange some minimally required data with them. Thus, WSNs are deployed (installed) quickly and without much knowledge of the environment. Existing experience with real WSNs and some theoretical foundations help installing more robust and self-sustainable networks than simply spreading them around the environment. However, the original dream of throwing sensor nodes out of an airplane to monitor thousands of square kilometers remains a dream.

The sensor network senses some phenomenon and needs to transfer the data to an external user. There is always something to sense out there: humidity, temperature, vibration, acceleration, sun radiation, rain, chemical substances, and many others. The main target of a sensor network is to sense some phenomenon and to transfer the gathered information to the interested user, typically an application residing somewhere outside the monitored area. The limited resources on the sensor nodes do not allow them to process the information extensively locally.

> The main functionalities of a sensor node are *sensing* and *sending*.

1.2 SAMPLE APPLICATIONS AROUND THE WORLD

Vineyard monitoring is one of the most classical examples of sensor network monitoring. The goal is to reduce water irrigation and to predict or discover vine sicknesses as soon as possible. This not only minimizes costs of growing the vines through less water usage, but also enables organic growing with low usage of pesticides. Sensors used include air temperature, air humidity, solar radiation, air pressure, soil moisture, leaf moisture, ultraviolet radiation, pluviometer (rain sensor), and anemometer (wind sensor). The sensors are typically spread over a large area of the vineyard and deliver their information to an external database, in which the information is processed by special environmental models. The results are shown to the scientist or to the vineyard farmer and can be automatically connected to the irrigation system. Figure 1.2 shows

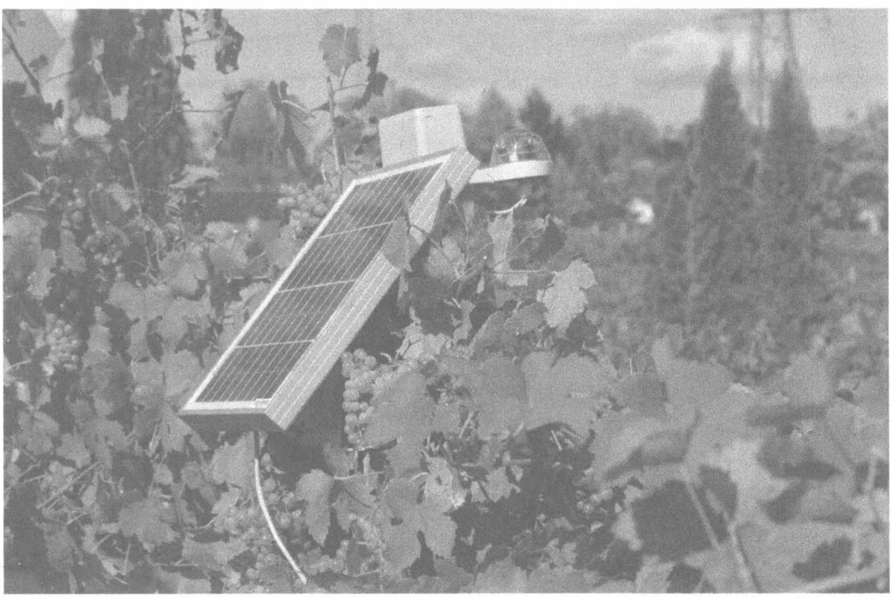

FIGURE 1.2 A sensor node from SmartVineyard Solutions installed in an organic vineyard in Slovakia. Reproduced with permission from SmartVineyard Solutions, Hungary.