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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.

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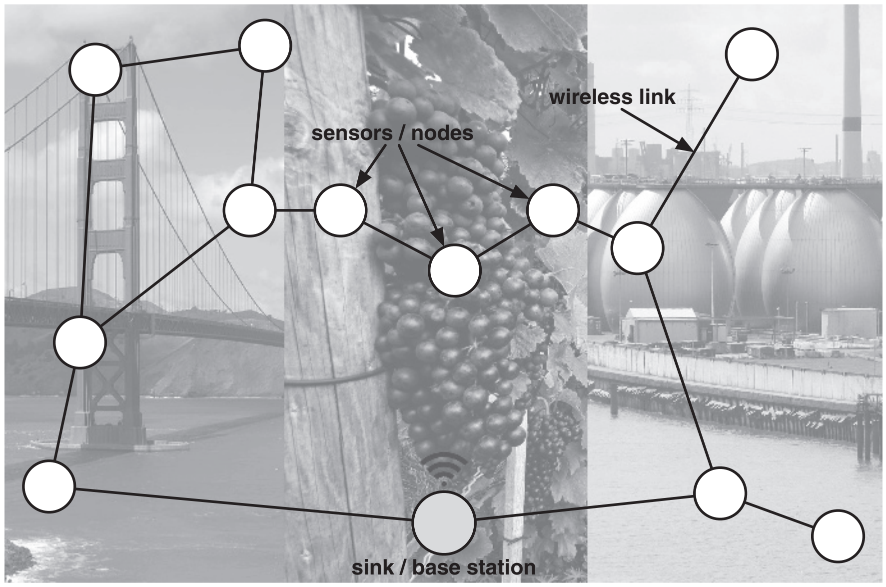

FIGURE 1.1 A typical sensor network with several sensor nodes and one base station. The sensors are connected to each other via wireless links, whereas the base station is typically more powerful and connected to the outside world. The application areas and environments are endless!

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.

a typical vine sensor node installed in a vineyard in Slovakia from SmartVineyard Solutions,[1] a Hungarian spin-off company.

A similar sensor network scenario is used for many other agricultural applications, often called precision agriculture. Examples are potato monitoring in Egypt [1], crop monitoring in Malawi [2], or a solution for vegetable monitoring on an organic farm in South Spain [3]. All of these systems have one problem in common: the foliage which develops over time. When the systems are first installed, the fields are almost empty or plants are small. However, as the crops grow, their foliage starts interfering with the system's work, particularly with its communications and sensors. Another common problem is that by harvesting time, the sensor nodes are well covered and hidden in the crops so their recovery is challenging. If unrecovered, they will most likely be damaged by the harvesting machines.

Bridge monitoring is a similar application in which the structural integrity of a bridge is monitored. Again, the space is limited, even if communication quality is better because of the outdoor, free-space environment. However, accessibility remains extremely limited.

There are two famous examples of bridges being monitored by sensor networks. The first example is tragic. On August 1, 2007, a bridge spanning the Mississippi river in Minneapolis collapsed suddenly under the weight of the rush hour traffic, killing 13 people and injuring another 145. The bridge was rebuilt shortly thereafter, this time equipped with hundreds of sensors to monitor its health and give early warnings.

The second example is more positive and presents the six-lane Charilaos Trikoupis bridge in Greece, which spans the Gulf of Corinth (Figure 1.3). It opened in 2003, with a monitoring system of more than 300 sensor nodes equipped with 3D accelerometers, tilt meters, tensiomag sensors, and many others. Shortly after opening, the sensor network signaled abnormal vibration of the construction's cables, which forced the engineers to install additional weights for stabilization. Since then the bridge has not had any further problems.

Fire detection is crucial to save life and prevent damages. Sensor networks can be efficiently employed to detect fires early and send an alarm with the fire's exact position to fire brigades. This idea has been used worldwide in countries such as Spain, Greece, Australia, and Turkey. The main challenge with this application is the sensor node hardware itself and its resistance to high temperatures. It is quite inefficient if the sensor network designed to detect fires fails on a hot day or at the first sparks of a fire. For these reasons, robustness of the hardware and smart, over-provisioned network design are essential. Furthermore, typically large remote areas have to be covered, which can pose problems for installation, maintenance, and communication.

Tunnel monitoring is another way in which sensor networks are used. Road tunnels are dangerous all over the world. If something happens, such as an accident or a fire, it is essential to know how many people are still inside and exactly where they are located. Even in normal situations, tunnels are a danger by themselves, as the light

[1] http://smartvineyard.com

FIGURE 1.3 The Charilaos Trikoupis bridge in Greece, with a sensor network installed with over 300 sensor nodes. In its first days, it signaled abnormal vibrations, which could be quickly fixed. Source: Guillaume Piolle, Flickr.

outside often blinds the driver when exiting the tunnel. The TRITon project[2] in Trento, Italy is an example of how to resolve these problems with sensor networks. Light sensors are used to adaptively regulate the light inside the tunnel to avoid both energy wasting and driver blinding. Video cameras are used to automatically detect cars and track them until leaving the tunnel for rescue operations. One of the main challenges of tunnel monitoring is the shape of the tunnel because wireless signals scatter significantly in such narrow environments and communications become obstructed and unreliable. Additionally, there is not much space to install many nodes and to make the network more robust. Working in tunnels is also difficult because the tunnel needs to be closed and guarded during work.

Animal monitoring is one of the oldest applications for sensor networks. These are not typical sensor networks because the main phenomena they sense are the movement of the animals. Thus, they function more as tracking applications, implemented with typical sensor nodes. Figure 1.4 shows how an Australian farm uses network sensors for cattle farming [4]. Instead of installing large area electric or other types of real fences, the cattle are equipped with a collar that has a positioning system with speakers and an electro-shocker. A web interface allows for drawing fences on a

[2]http://triton.disi.unitn.it

FIGURE 1.4 Virtual fences sensor network for cattle farms in Australia. Source: CSIRO, Australia.

virtual map, identifying where the cattle should or should not be. If a cow tries to cross the boundary to a locked area, it first receives an acoustic signal. If that does not work and the cow stays in the prohibited area, a light electro shock is given (similar to the ones given by electric fences). The cows quickly remember that the acoustic signal is followed by the electric one and learn to react quickly and leave the locked area.

Additionally, the movement of the cattle can be used to evaluate their fitness. Other sensors can even monitor their temperature which allows for further health monitoring. This is especially important for large area cattle farms such as those found in Australia or South America.

Animal recognition is yet another area of animal monitoring. One of the first applications of wireless sensor networks was developed in Australia to search for the cane toad, a special toad species. The history of the cane toad is worth knowing. The cane toad is native to South and Central America but was introduced in Australia in 1935 to fight grey backed beetles, a species threatening the cane fields. However, this introduction was not very successful since grey beetles live on the tops of the cane but the cane toad is not a very good climber. Thus, the cane toad ignored the beetles and instead began eating other native species such as lizards. The cane toad population grew to such an extent that local rangers purposefully began killing them, yet they hid well.

In this case, the uniqueness of the sensor network is its sensor. It literally listens to the forest's sounds to recognize the specific quaking of a cane toad. Once recognized, an event is generated and sent along with the cane toad's coordinates to local rangers who then can physically find it. This was a significant increase in efficiency because previously the rangers did the work of the sensor network and went to listen for the cane toad's quaking.

Technically, the sensor network is not trivial to implement. It requires on-board audio processing to identify the cane toad quaking, which also requires sufficient on-board resources. The full system was described several years after the deployment by Hu *et al.* [5].

There are many different applications of wireless sensor networks around the world making it impossible to cover all their application areas here in this book. The interested reader should simply search the Internet for further applications and examples of wireless sensor networks as most of them are well described.

1.3 TYPES OF WIRELESS SENSOR NETWORKS

Recently, various new definitions and buzzwords have emerged in the area of sensor networks. This section explores them in more detail.

Wireless sensor network is still one of the main terms for describing a network of cooperating tiny computers that are able to sense some phenomenon in the environment and send their results to a central entity such as a database or a server. The term is often used for installations, which work in the traditional way of sense and send. However, it can be seen also in broader contexts, depending on who is using the term and where.

Cyber-physical system (CPS) is a newer term for a wireless sensor network. It attempts to better describe what you can actually do with these networks and their main properties when being integrated into a physical environment. Different from other computers and devices, which are environment agnostic, cyber-physical systems are part of the environment and application restricted. Another important property is the fact that they also can affect the environment via so-called *actuators* such **actuators** as in automatic irrigation pumps, light switches, alarms, and humidity or temperature regulators. Interestingly, the term wireless is no longer used in cyber-physical systems. The reason being, many sensor networks are now wired, since power supply in buildings is easier to maintain through wired connections than through wireless ones. Smart homes are a typical example of cyber-physical systems (Figure 1.5) as are smart grids and smart cities.

Body sensor networks refer to a specific type of network, designed to be carried on the body (mostly human). Applications include health monitoring, weight

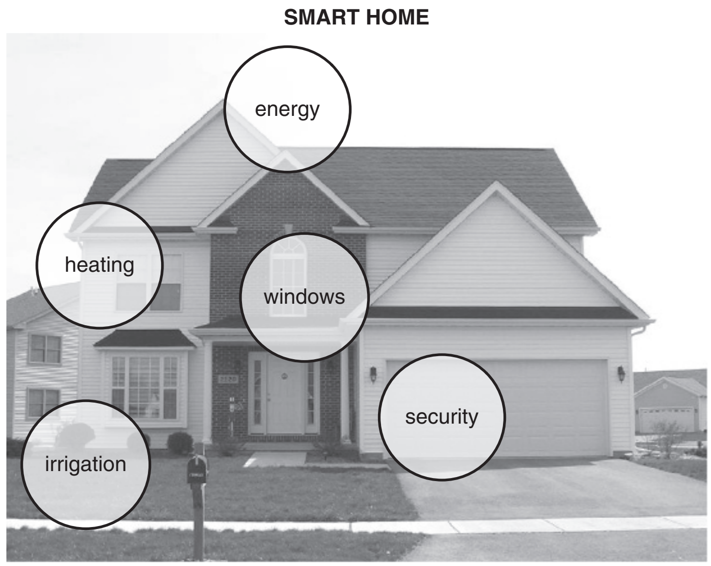

FIGURE 1.5 A typical example of a cyber-physical system is the smart home application in which various sensors and actuators are combined for the convenience of the users.

management, sports logging, and many others. There are some peculiar examples, such as smart shoes or smart T-shirts, which are able to sense your activity or heart rate. Most of the sensor nodes are tiny, sometimes even implantable. The current trend is clearly moving towards one integrated device that can sense all functions, instead of several different sensors on various parts of the body. The whole sensor network often degrades into one or very few devices, such that the term network becomes meaningless. Figure 1.6 presents an example of body sensing.

Participatory sensing, collaborative sensing, or crowdsourcing refers to a new and fast developing type of sensing in which sensors are essentially humans with their smartphones. For example, people can track their biking paths and then evaluate them in terms of safety, noise, or road quality. All this data are gathered on a central point and processed into a single biking quality map of a city, which can be distributed to any interested user [6]. The real power of these applications is that no additional hardware is needed, only a rather simple user-oriented application for smart phones. At the same time, this is also the largest challenge in these applications—motivating people to join the sensing process and to deliver high quality data. Privacy is a big issue with these applications because it requires people to share their location data.

The Internet of Things (IoT) is often mistaken to be a sensor network. However, IoT's main concept is that all things, such as a washing machine or radio, are

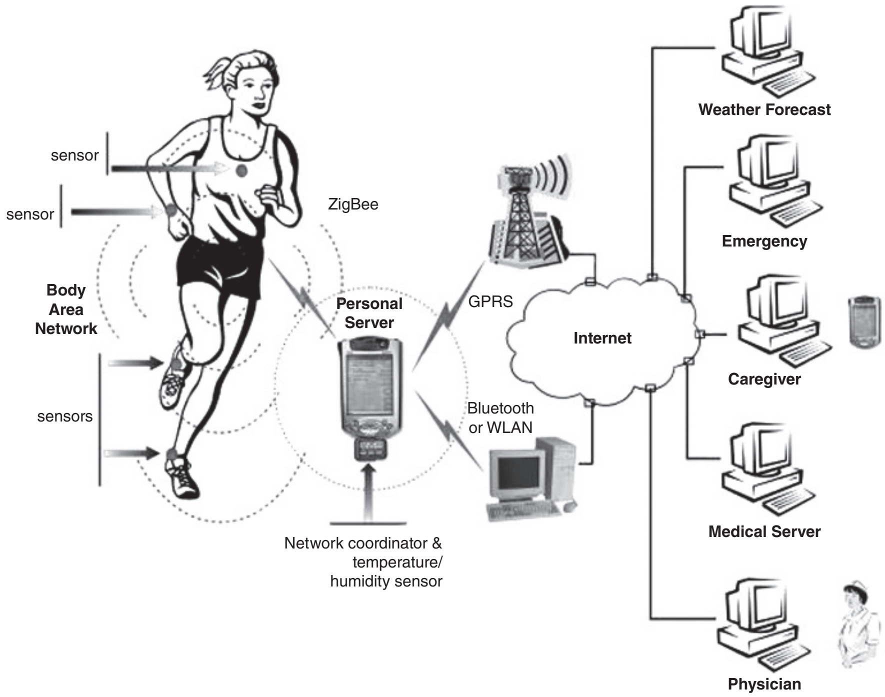

FIGURE 1.6 A body sensor network consists of relatively few sensors on or in the body of a human. Source: Wikipedia.

connected to the Internet. The Internet connection has significant advantages when implementing sensor networks and can thus be seen as an enabling technology. However, the target can also be very different, e.g., when you can read your emails from the microwave or from your car. The term Internet is also a hint that usually these networks are IP enabled and thus use a well-defined communication stack. This can be seen as an advantage (no need to reimplement) or as a disadvantage (high energy use, little flexibility).

Figures 1.5 and 1.6 present some of the preceding network types, a cyber-physical system for a smart home application and a body area network for health monitoring. The common property of all these applications and types is that the system is highly integrated with its respective environment and cannot be easily transferred or generalized.

> Regardless of the exact term used—wireless sensor networks, sensor networks, body networks, or cyber-physical systems—the most important topics remain *sensing*, *communication*, *energy management*, and *installation*.

SUMMARY

Wireless sensor networks are a modern technology covering the general application area of monitoring. They typically consist of many (few to thousands) devices to enable large-scale monitoring. The main requirements of WSNs are to be *small-size* and *low-cost*. Thus, instead of implementing complex applications in the network itself, the sensor network performs two main operations: *sensing* and *communicating* the sensed data to each other and to a central server.

Applications of wireless sensor networks span environmental and animal monitoring, factory and industrial monitoring, agricultural monitoring and automation, health monitoring and many other areas. One of the main characteristics of wireless sensor networks is that they are tightly *coupled with their application*. A system developed for agricultural monitoring in one place can hardly be used in another place and is almost impossible to use in animal monitoring.

FURTHER READING

All of the readings presented in this chapter refer to detailed descriptions of a particular sensor network application.

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