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Introduction

During recent years, wireless network technologies have achieved a key role as the media for telecommunications. Whereas wired networks provide only fixed network topologies, wireless networks support low-cost and effortless installations, ad hoc networking, portability of network devices, and mobility of network users. Together with the growth of network and processing capacities, the application area of wireless networks has extended from limited speech and broadcast TV services into high-speed data transfer and multimedia. At the other end of the wireless technology spectrum, where no real-time multimedia is present, the need for low-cost, low-rate, and very low-power technologies has emerged. Devices supporting multiple wireless technologies and objects with embedded networking capabilities are appearing and envisioned to provide ubiquitous services.

1.1 Overview of Wireless Technologies

From the technology spectrum point of view, wireless communication can be categorized according to their typical applications, data rates, and coverage. Table 1.1 illustrates the generally known classification that originates from the Institute of Electrical and Electronics Engineers (IEEE). The values presented in the table are not definitive; rather they are provided for perceiving the relationships of the different classes. The wireless transceiver is assumed to be a radio although other wireless physical layers, such as infrared, can be used as well.

Wireless Wide Area Networks (WWANs) and Wireless Metropolitan Area Networks (WMANs) provide the widest geographical coverage. The highly utilized WWANs mainly consist of traditional digital cellular telephone networks and their extensions for data services and higher speeds, such as Global System for Mobile Communications (GSM) and Universal Mobile Telecommunications System (UMTS). Communication satellites belong to this class as well. WMANs are emerging technologies developed for broadband network access as an alternative to cable networks and Digital Subscriber Lines (DSLs) in homes and enterprises. Examples of WMANs are IEEE 802.16, its mobile extensions and the High-Performance Radio Metropolitan Area Network (HIPERMAN).

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Table 1.1 A classification of wireless communication technologies.

Class	Data rate	Radio coverage	Typical applications	Exemplar technologies
WWAN	<10 Mbps	>10 km	Telephony, mobile Internet	GSM, UMTS, satellite
WMAN	<100 Mbps	<10 km	Broadband Internet	IEEE 802.16, HIPERMAN
WLAN	<100 Mbps	<100 m	Wired LAN replacement	IEEE 802.11, HIPERLAN/2
WPAN	<10 Mbps	<10 m	Personal data transfer	Bluetooth, IEEE 802.15.3
WSN	<1 Mbps	<1 km	Monitoring, control	proprietary, IEEE 802.15.4, RFID

Wireless Local Area Networks (WLANs) have rapidly gained popularity on the wireless markets. WLAN was originally developed for extending or replacing wired computer Local Area Networks (LANs), in cases where fixed cabling was costly or impossible due to mobility, short network lifetime, or historic value of the buildings. At the moment, WLAN is widely employed for providing network access in public buildings and enterprises, and for municipal network implementations. WLAN has also extended to home networking, including consumer electronics and household appliances.

The de facto WLAN technology is IEEE 802.11, and its numerous extensions for higher communication speeds, Quality of Services support, security, and mesh networking. Different standards and industry specifications, such as High-Performance Radio Local Area Network type 2 (HIPERLAN/2), Home Radio Frequency (HomeRF) and Digital Enhanced Cordless Telecommunications (DECT) have mainly remained at the level of standardization with small product volumes.

The class in close relation to WLANs is comprised of Wireless Personal Area Networks (WPANs), such as Bluetooth and IEEE 802.15.3. WPANs are generally targeted at data communications between personal devices, including Personal Digital Assistants (PDAs), mobile phones, headsets, and laptops. WPANs are also used for low-rate and low-power communications, e.g. in automation and alarm systems. Furthermore, WPAN technologies can be used for providing wireless access to an infrastructure LAN (Bluetooth) and for enabling high-speed multimedia content delivery (IEEE 802.15.3). Hence, WPANs are not clearly distinct from WLANs, sharing the same operational environments and application domains. The differences are in the non-functional requirements, such as cost, power, and networking range.

Wireless Sensor Networks (WSNs) (Kuorilehto et al. 2005b; Stankovic et al. 2003) is an emerging class of wireless technologies that has recently aroused much interest in industry and academic research, and which is envisioned to create massive markets in next few years. WSNs consist of independent, collaborating, highly resource-constrained nodes and actuators that sense, process, store, and deliver data.

In contrast to WLANs and WPANs, WSNs are seen as larger scale, self-organizing, and strictly application-oriented rather than measured by the coverage of a single radio cell or the nominal capacity of a link. Thus, the network coverage can vary from centimeters to hundreds of meters and kilometers and the network can grow to thousands of nodes, while the data rates are in the order of bits/s (Kuorilehto et al. 2005b). The network performance is measured by its capability to serve the implemented applications.

Compared to traditional communication networks, there is no pre-existing physical infrastructure that restricts the topology. Recourses are constrained in the means of, for example, size, cost, memory, and especially energy, which is seen as the most limiting factor for mass applications and is the area that we have chosen as a special topic in this book.

WSNs have been implemented as proprietary solutions (Kuorilehto et al. 2005b). The recent standardized technology supporting WSN implementations is IEEE 802.15.4 (IEE 2003b), which is utilized by networks implemented according to the ZigBee specification (Zig 2004). The Radio Frequency Identification (RFID) technology can be seen to belong to the class of WSNs as well with limited scaling and networking performance.

This book concentrates on WSNs, specifically on the design, implementation, and deployment of ultra-low energy WSNs for different application domains.

WSNs are typically ad hoc networks (Stallings 2004) but there are major conceptual differences. First, WSNs are data-centric with an objective to deliver time-sensitive data to different destinations. Second, a deployed WSN is application-oriented and performs a specific task. Third, messages should not be sent to individual nodes but to geographical locations or regions defined by data content. In WSNs, quantitative requirements in terms of latency and accuracy are strict due to the tight relation to the environment. In general, the capabilities of an individual sensor node are limited, but the feasibility of WSN lies on the joint effort of the nodes (Stankovic et al. 2003).

1.2 TUTWSN

The DACI (Design, Applications, Communication, and Implementation) research group at Tampere University of Technology has been actively developing novel short-range wireless network technologies and applications since 1997. The Tampere University of Technology Wireless Sensor Network (TUTWSN) research contains both theoretical and experimental methods, in the extent that we implement full-scale prototypes.

Also, we have been concentrating on the whole problem area, from applications to low-level power optimization algorithms. We use the term TUTWSN framework to address a variety of general problems, open questions, and real-life deployments in the WSN field. The use of TUTWSN should be considered as best practice according to our analysis. Non-inclusion of the term "TUTWSN" suggests that the same fundamental research problems and best solutions apply as presented in this book.

The framework comprehends the methods, algorithms, and implementation that we have found to be suitable or optimal according to certain requirements. Thus, TUTWSN is not a single WSN realization, but contains numerous design choices and practices that are applicable or necessary when moving from theory to real-life deployments. We are not concentrating on theory for the sake of theory, but to present a path from theory to practical implementations. We believe that an indepth coverage of the commonly known features of WSN is not needed, and thus kept in minimum. Due to book's emphasis on practice, we need to have real-life implementations for making real-life comparisons between technologies and design choices.

Also, as we will conclude, WSNs need cross-layer design for achieving performance or operability in the first instance. The cross-layer means that we cannot design separate protocol layers and set their parameters independently of each other, since a simple function on the upper layer protocol can result in massive transactions with the lower layer, consuming the available energy and blocking the existing network operation. Having said that, this does not mean that a protocol stack has to be designed from scratch every time we need to support a new application, just that we need to efficiently reuse the available functional components. These components are standard protocols and their parts; operating systems, application programming interfaces, databases, radio transceivers, etc. The management and optimization of functionality creates a large design space, which requires methods and tools to meet the functional and non-functional needs of the applications.

We need to address entire protocol stacks, applications, and operation environments. Most weight is still attributed to the layers that significantly affect the end result, i.e. layers 2 and 3 (MAC and routing) and their implementations.

1.3 Contents of the Book

This book is divided into five parts. Part I; just discussed, provides an introduction to the various wireless technologies and WSNs. Part II presents the design space of WSNs by defining the requirements, a WSN design flow, and WSN standards. This part also covers sensor platform design approaches and lists various platforms in example. Part III describes the WSN protocol stack and presents related WSN protocol proposals for each layer. Software architecture is considered by examining middleware and application layers, as well as light-weight operating systems suited for WSNs. Quality of Service (QoS) and security issues are discussed in respect of WSNs. Part IV presents TUTWSN as an extensive example of a protocol stack and software architecture that is completely designed for WSNs. The part also presents Wireless Sensor Network Simulator (WISENES) design and evaluation environment targeted at developing WSN protocols. A separate chapter is devoted to protocol analysis models comparing TUTWSN and ZigBee protocols. Part V presents the TUTWSN deployment architecture ranging from sensor network to back-end tools for refining the gathered data. Several sensor application use cases are discussed, while presenting extensive experiences on real-life deployments related to each use case. Part VI concludes the book.