UWB
Communication Systems
A Comprehensive Overview

Edited by: Maria-Gabriella Di Benedetto, Thomas Kaiser, Andreas F. Molisch, Ian Oppermann, Christian Politano, and Domenico Porcino

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Contents

Preface

Ultra-wideband (UWB) communication systems offer an unprecedented opportunity to impact the future communication world. The enormous available bandwidth, the wide scope of the data rate/range trade-off, and the potential for very-low-cost operation, which will lead to pervasive usage, all present a unique opportunity for UWB systems to impact the way people and intelligent machines communicate and interact with their environment. In particular, UWB is a promising area offering enormous advantages for short-range communications. Nevertheless, the technology still requires much work from the research community as well as solid proof of its viability in the commercial world before it can claim to be successful.

The world of UWB is changing rapidly, and it may be argued that the information contained in any general text on the subject is obsolete before the ink has dried. Even between the writing of the manuscript (Winter 2004) and the actual production, we have seen a number of interesting developments in the field. Our book attempts to provide an understanding of the (longer-term) fundamentals of UWB, the major research and development challenges, as well as a snapshot of the work in progress addressing these challenges. Due to the rapid progress of multidisciplinary UWB research, such a comprehensive overview can generally be achieved by combining the areas of expertise of several scientists in the field.

More than 30 leading UWB researchers and engineers have contributed to this book, which covers the major topics relevant to UWB. These topics include UWB signal processing, UWB channel measurements and modelling, higher-layer protocol issues, spatial aspects of UWB signalling, UWB regulation and standardisation, implementation issues, UWB applications, and positioning with UWB systems.

The book is targeted at advanced academic researchers, wireless designers, and graduate students wishing to greatly enhance their knowledge of all aspects of UWB systems. The reader should be left with a high-level understanding of the potential advantages of UWB in terms of high-data-rate communications, and location and tracking capabilities.

Due to the sheer number of authors who have contributed to this book and many others involved, it is difficult to equally thank them all, so we generally apologize for the absence of personal acknowledgements.

Introduction

This introductory first chapter by I. Oppermann is intended to give the reader a high-level understanding of the scope and the role of UWB as well as some appreciation for the difficult "birth" UWB has experienced in the crowded world of communication standards. The enormous bandwidth and very low power spectral density of UWB make it difficult to detect; therefore it is potentially difficult to operate in such as way as to realise these benefits. The nature of UWB also leads to very significant technical difficulties, which are then compounded by regulatory and commercial resistance to UWB as a technology. The introduction covers some of the basic UWB signal generation techniques, working definitions of UWB, the on-going regulatory situation broad application areas and current research focus areas.

UWB propagation channels

Chapter 2 describes the propagation of UWB radiation from the transmitter to the receiver, covering the physical processes of the propagation as well as the measurement and modelling of the channels. The first section by A. F. Molisch is an introduction that outlines the basic properties of UWB propagation channels (as compared to the well-known narrowband channels) and also gives a synopsis of the subsequent sections. Section 2.2, "Measurement techniques," by J. Kunisch describes how to measure the transfer function or impulse responses of UWB channels and pays particular attention to the impact of the antennas used during the measurement. As it is desirable to isolate the impact of the channel (without the antennas), the de-embedding of the antenna effects becomes of paramount importance. Next, Section 2.3 by R. Qiu describes the fundamental propagation effects for UWB radiation. In particular, the diffraction of an ultra-wideband wave (corresponding to a short pulse) by a half-plane is a canonic problem that is analysed. It is shown that the pulse is distorted during that process; this has important consequences for the design of optimum receiver structures (matched filters). After those fundamental investigations, Section 2.4 to Section 2.6 describe statistical channel models. Section 2.4 by D. Cassioli gives an overview of measurements and models of path loss and shadowing, which describe the large-scale channel attenuation. Section 2.5 by A. F. Molisch and M. Buehrer then analyses the small-scale fading and delay dispersion effects that are caused by the multipath propagation. This section also investigates the frequency selectivity of the reflection coefficients of various materials and shows that it can lead to similar distortions of each multipath component as the diffraction effects described in Section 2.3. Finally, Section 2.6 by M. Pendergrass describes a standardised channel model established by the IEEE 802.15.3a group. This model, which is suitable for indoor environments with distances of up to 10 m, has been used for the evaluation of various high-data-rate UWB systems. Another type of system is body area networks, where various devices mounted on a human body communicate via UWB radiation. This rather unique environment gives rise to new challenges in the channel measurement and modelling. Section 2.7 by I. Z. Kovács, G. F. Pedersen, and P. C. F. Eggers describes such channels. Finally, Section 2.8 by S. Roy and I. Ramachandran gives an overview of channel estimation techniques for both OFDM-based and impulse-radio-based UWB systems.

Signal processing

This chapter addresses signal processing issues in UWB. The first three sections by I. Oppermann, M. Hämäläinen, J. Iinatti, and A. Rabbachin, present both impulse radio techniques and multiband techniques. UWB systems may be primarily divided into impulse radio (IR) systems and multiband systems. Multiband systems offer the advantage of potentially efficient utilisation of spectrum, while IR systems have the advantage of simplicity, and thus have potentially lower cost. The IR UWB concepts investigated support many modulation schemes including orthogonal and antipodal schemes. However, the basic modulation must also include some form of spectrum randomisation techniques to limit the interference caused by the transmitted pulse train. Both time-hopping (TH) and direct-sequence (DS) randomisation techniques were examined. Deciding which modulation scheme to use depends on the expected operating conditions and the desired system complexity. Section 3.4 by B. Allen, S. A. Ghorashi, and M. Ghavami introduces the application of impulses to UWB wireless transmissions. A number of candidate pulse waveforms are characterised in the time and frequency domains. The application of orthogonal pulse waveforms is introduced. These waveforms enable advanced modulation and multiple-access schemes to be implemented. The success of these schemes, however, is determined by the extent of pulse distortion caused by the transmitter and receiver circuitry and the propagation channel. Thus, distortion mitigation techniques are required. The issue of coexistence of impulse radio with other spectrum users is also discussed. Section 3.7 by I. Oppermann, M. Hämäläinen and J. Iinatti discusses synchronisation in IR systems. After a brief introduction of optimal synchronisation schemes, a more realistic approach is investigated in closer detail. Finally, the last Section by O. Albert and C. F. Mecklenbräuker presents a UWB radio testbed based on pulse position modulation (PPM) for investigating the properties of short-range data communication. The testbed is designed to realise data transmission at 6 Msymb/s over a distance of a few meters in indoor office environments. The focus of this effort is on the implementation of commercial-grade microwave circuitry and algorithms for ultra-wideband data transmission, especially concerning mobile battery-driven devices. The testbed hardware is described in detail as well as the two-stage approach used for receiver synchronisation.

Higher-layer issues: ad hoc and sensor networks

In the last few years, the increasing interest in applications based on the deployment of ad hoc networks has triggered significant research efforts regarding the introduction of the energy-awareness concept in the design of medium access control (MAC) and routing protocols. Chapter 4, which was edited by M.-G. Di Benedetto and includes contributions by L. De Nardis, S. Falco, and M.-G. Di Benedetto, investigates this issue in the context of UWB, ad hoc, and sensor networks. Progressing from the analysis of the state of the art in energy-efficient MAC and routing protocols, the chapter presents an innovative energy-aware MAC and routing solution based on the position information provided by UWB by means of a distributed positioning protocol.

Ad hoc networks are considered as a viable solution for scenarios in which fixed infrastructure and, consequently, unlimited power sources are not available. In such scenarios, an efficient management of the limited power supply available in each terminal is a key element for achieving acceptable network lifetimes. This is particularly true for sensor networks, for which long battery duration is one of the basic requirements, given the typical size of such networks (up to thousands of terminals), as will be analysed in Section 4.1 by L. De Nardis and M.-G. Di Benedetto.

Location information is another valuable way of achieving energy awareness in ad-hoc networks. In Section 4.2, by L. De Nardis, we will first review location-aware routing protocols with a focus on power efficiency. We then address the problem of information exchange through the network by means of specifically designed protocols.

Next, we introduce in Section 4.3, by L. De Nardis, a MAC protocol that foresees a dedicated procedure for the acquisition of distance information and is tailored on UWB features.

Section 4.4, by L. De Nardis and S. Falco, analyses the effect of mobility on the behaviour of the proposed MAC and routing strategies.

Spatial aspects of UWB

The aim of this chapter is to discuss the spatial aspects of the UWB radio channel from various perspectives. In the second section by J. Kunisch, a spatial model is presented based on measurement data that was obtained in office environments with line-of-sight, non-line-of-sight, and intermediate conditions. The distinguishing feature of the ultra-wideband indoor radio channel is that certain individual paths are recognisable and resolvable in the measurements, which are adequately reflected by the proposed spatial model. Moreover, the model also covers movements of the receiving or of the transmitting antennas on a small scale (several wavelengths). In Section 5.3 by W. Sörgel, C. Waldschmidt, and W. Wiesbeck, the state-of-the-art UWB antenna array concepts and their applications are introduced. Simulation results for a linear exponentially tapered slot antenna array (Vivaldi antennas) for time domain beam steering are given, and further theoretical modelling is substantiated by experimental results. F. Argenti, T. Bianchi, L. Mucchi, and L. S. Ronga present in Section 5.4. a two-transmit-antenna scheme with orthogonal polarisation in order to uniformly cover an indoor area. A single antenna receiver results in a 2×1 MISO (multiple-input single-output) system so that space-time coding becomes applicable. The goal is to employ the polarisation diversity in order to obtain quality constant symbol detection while the receiver moves around within the covered area. Section 5.5 by A. Sibille addresses several basic issues pertaining to spatial diversity in UWB systems. It mainly concentrates on impulse-based radio, but it also evokes effects concerning frequency domain modulation schemes such as OFDM. The main subjects are the impact of electromagnetic coupling between sensors and the impact of channel properties (like fading and angular variance) on spatial diversity. Besides the two main pillars of MIMO signal processing, namely, spatial multiplexing and space-time coding, the third and most classical one is *beamforming*, which is revisited in Section 5.6 by S. Ries, C. Senger, and T. Kaiser. Since the pulse duration is shorter than the travel time between two colocated antennas, beamforming for UWB signals has some special properties that are different from the narrowband case. For instance, because of the absence of grating lobes in the beam pattern, the spacing of the array elements is not limited by half of the wavelength, so that high resolution can be achieved with only a few array elements. At the end of this chapter the principal feasibility of direction-of-arrival (DoA) estimation is shown by an illustrative example. In Section 5.7 by W. P. Siriwongpairat, M. Olfat, W. Su, and K. J. Ray Liu, the performance of UWB-MIMO systems using different models for the wireless channels and different modulation schemes is presented. In particular, the performance merits of UWB-ST-coded-systems employing various modulation and multiple-access techniques, including time-hopping (TH) M-ary pulse-position modulation (MPPM), TH binary phase-shift keying (BPSK), and direct-sequence (DS) BPSK, are mentioned. At the end, the application of multiple transmit and/or receive antennas in a UWB-OFDM system is discussed. The last section by F. Zheng and T. Kaiser presents an evaluation of ergodic capacity and outage probability for UWB indoor wireless systems with multiple transmit and receive antennas (multiple-input multiple-output, MIMO). For some special cases, analytic closed-form expressions for the capacity of UWB wireless communication systems are given, while for other cases the capacity is obtained by Monte Carlo simulation approach. The contribution reveals that the UWB MIMO communication rate supportable by the channel increases linearly with the number of transmit or receive antennas for a given outage probability, which is reminiscent of the significant data rate increase of MIMO narrowband fading channels.

UWB ranging

One of the most innovative features of ultra-wideband technology is the very-high temporal resolution associated with the typical spread of UWB energy over large frequency bands. This feature has inspired and is still inspiring a new generation of technical developments and applications looking at the challenges of detection of the location of people and objects (people and asset tracking, smart spaces, ambient intelligence). Chapter 6 of this book introduces the reader to the basics of location technology via UWB systems. An analysis of the main potential and practical techniques with their accuracy is presented in Section 6.2 by A. Ward. In Section 6.3 by A. Ward and D. Porcino, a comparison with alternative radio-based systems is closely considered, while the main implications on the physical layer of a radio design and a sample RF link budget are discussed in Section 6.4 by D. Porcino. In the next section, results and advantages are then presented from commercial fine-grained UWB positioning systems by A. Ward, leading the discussion to operations in very challenging propagation conditions (such as metal cargos) where the signal distortion is very significant and makes ranging calculations very difficult. These issues are part of Section 6.6 by D. Porcino. An experimental antenna-array system is then introduced in Section 6.7 by J. Sachs and R. Zetik, with test results showing the limits of what has been achieved today in terms of maximum positioning accuracy in controlled situations. In the last section by A. Ward, the important aspects of system integration of UWB positioning technology in the real world of complex buildings, hospitals, and houses are presented with attention given to the requirements that this technology will put onto system integrators and designers. This chapter guides the reader with a language suitable to comprehend the basic principles of the promising UWB ranging features, which are about to be widely explored in the commercial world.

Regulation and standardization

Since typical UWB radio may use part of the radio frequency spectrum already assigned to operative primary or secondary radio services, UWB radio devices—despite their extremely low transmission output power—may be a potential source of interference for incumbent radio services and should provide the ability to coexist with legacy radio services. In this chapter, we provide the reader with a comprehensive description of the worldwide UWB regulation and standardization framework under completion in order to elaborate on novel and effective means of spectrum management based on coexistence mechanisms instead of using conventional frequency sharing mechanisms. The first section by C. Politano is dedicated to regulation aspects for UWB communication and positioning applications to operate without requirement for individual right to use radio spectrum ("license-exempt"), and on a "no protection, no harmful interference" basis. This section introduces the UWB regulation framework elaborated under ITU-R to allow UWB devices and provides a detailed overview on the European regulatory approach in order to explain how prudent but constructive regulation rules are elaborated in this region. The second section by W. Hirt presents UWB standardization overview in the USA and in Europe. It provides the global overview of IEEE working groups mandated for wireless personal area network (WPAN) including high-data-rate (IEEE802.15.3a) and low-data-rate (IEEE802.15.4a) communication applications, and introduces the most popular UWB technology candidates identified during the year 2004. Then in this section, the European standardization process is also presented with an overview of the ETSI-TG3 working group mandated by the ECC for the definition of "harmonised standards for short-range devices (SRD) using UWB technology." The last section by R. Guiliano describes the methodology "compatibility study" for evaluating UWB interferences risk with incumbent radio services and presents some evaluation results of compatibility studies conducted for a few coexistence scenarios between UWB and UMTS, and fixed services (PP, PMP). The particular interest of this section is the description of the UWB characteristics that are impacting compatibility studies (activity factors, traffic characteristics, radio access modes) and how interference risks may be reduced by applying these features, allowing incumbent radio receivers to coexist with UWB devices. The results of such compatibility studies have been used for the elaboration of mitigation techniques (proposed for standardization) in order to specify coexistence mechanisms to reduce UWB interferences with incumbent radio services.

Maria-Gabriella Di Benedetto, Thomas Kaiser, Andreas F. Molisch,
Ian Oppermann, Christian Politano, and Domenico Porcino
March 2006

1 Introduction

Ian Oppermann

1.1. Introduction

Ultra-wideband (UWB) communication systems have an unprecedented opportunity to impact communication systems. The enormous bandwidths available, the wide scope of the data rate/range tradeoff, and the potential for very-low-cost operation leading to pervasive usage, all present a unique opportunity for UWB to impact the way people interact with communications systems.

The spark-gap transmission experiments of Marconi in 1901 represent some of the first experiments in a crude form of impulse radio. Pioneering contributions to modern UWB radio were made by Ross and Bennett [1] and Harmuth [2]. The earliest radio communications patent was published by Ross (1973). In the past 20 years, UWB has been used for radar, sensing, military communications, and niche applications.

A substantial change occurred in February 2002 when the US Federal Communications Commission (FCC) [3, 4] issued a ruling that UWB could be used for data communications as well as radar and safety applications. This book will focus almost exclusively on the radio communications aspects of UWB.

The band the FCC allocated to communications is 7.5 GHz between 3.1 and 10.6 GHz; by far the largest allocation of bandwidth to any commercial terrestrial system. It was little wonder that efforts to bring UWB into the mainstream were greeted with great hostility. First, the enormous bandwidth of the system meant that UWB could potentially offer data rates of the order of Gbps. Second, the bandwidth was overlaid on many existing allocations, causing concern from those groups with the primary allocations. When the FCC proposed the UWB rulings, they received almost 1000 submissions opposing the proposed rulings.

Fortunately, the FCC UWB rulings went ahead. The concession was however that available power levels would be very low. At the time, the FCC made it clear that they were being deliberately cautious with the setting of the maximum power masks. If the entire 7.5 GHz band is optimally utilized, the maximum power available to a transmitter is approximately 0.5 mW. This is a tiny fraction of what is

2 UWB propagation channels

Andreas F. Molisch, Jürgen Kunisch, Robert Qiu, Dajana Cassioli, Michael Buehrer, Marcus Pendergrass, István Z. Kovács, Gert F. Pedersen, Patrick C. F. Eggers, Sumit Roy, and Iyappan Ramachandran

2.1. Introduction

2.1.1. General aspects of channel modeling

As with any other communications system, it is the *channel* that determines the ultimate (information-theoretic) performance limits, as well as the practical performance limits of various transmission schemes and receiver algorithms. For UWB systems, this channel is the ultra-wideband propagation channel. Understanding this channel is thus a vital prerequisite for designing, testing, and comparing UWB systems. Just like UWB communications itself, channel modeling for UWB is a relatively new area. And just as the interest for UWB systems has intensified in the last years, so has the importance of modeling the UWB propagation channels. In this chapter, we will give a comprehensive overview of the state of the art in this exciting area.

Quite generally, wireless channel modeling is done for two different purposes.

(i) Deterministic channel modeling tries to predict the behavior of a wireless channel in a specific environment. If a complete description of the geometry, as well as of the electromagnetic properties of the materials, of the surrounding of transmitter and receiver is given,[1] then Maxwell's equations can be solved exactly, and the channel impulse response (or an equivalent quantity) can be predicted. This approach, which had long been deemed too complicated, has become popular in the last 15 years. Ray tracing and other high-frequency approximations, as well as the advent of more powerful computers, have made it possible to perform the required computations within reasonable time.

(ii) Stochastic channel models try to model the "typical" or "canonical" properties of a wireless channel, without relating those properties to a specific location. As the most simple example, the probability density

[1]The size of the "surroundings" depends on the environment, as well as on the desired dynamic range.

3 Signal processing

Ian Oppermann, Matti Hämälainen, Jari Iinatti,
Alberto Rabbachin, Ben Allen, Seyed A. Ghorashi,
Mohammad Ghavami, Olaf Albert,
and Christoph F. Mecklenbräuker

3.1. Introduction

Many different pulse generation techniques may be used to satisfy the requirements of a UWB signal. As discussed in the previous chapters, the FCC requires that the fractional bandwidth is greater than 20%, or that the bandwidth of the transmitted signal is more than 500 MHz, whichever is less. The FCC also stipulates peak power requirements [1]. Many possible solutions may be developed within these restrictions to occupy the available bandwidth.

UWB systems have historically been based on impulse radio concepts. Impulse radio refers to the generation of a series of very short duration pulses, of the order of hundreds of pico seconds. Each pulse has a very wide spectrum that must adhere to the spectral mask requirements. Any given pulse will have very low energy because of the very low power levels permitted for typical UWB transmission. Therefore, many pulses will typically be combined to carry the information for one bit. Continuous pulse transmission introduces a complication in that, without further signal processing at the transmitter, strong spectral lines will be introduced into the spectrum of the transmitted signal. Several techniques are available for minimising these spectral lines, the most common of which are described later in this chapter.

Impulse radio has the significant advantage in that it is essentially a baseband technique. The most common impulse-radio-based UWB concepts are based on pulse position modulation with time hopping (TH-PPM). Time-hopping, direct-sequence techniques, and multicarrier schemes are also described in this chapter. However, the focus will be on impulse radio modulation schemes.

This chapter will address signal processing issues in UWB. The chapter will address both impulse radio techniques and multiband techniques.

4 Higher-layer issues: ad hoc and sensor networks

Maria-Gabriella Di Benedetto, Luca De Nardis, and Salvatore Falco

4.1. Introduction

Ultra-wide-band (UWB) radio has the potential of allowing simultaneous communication of a large number of users at high bit rates [1–3]. In addition, the high temporal resolution inherent to UWB provides robustness against multipath fading and is particularly attractive for indoor local area network (LAN) applications. UWB is also capable of recovering distance information with great precision. As we will show later in this chapter, distance and position data can lead to better organization of wireless networks, for instance, through better resource management and routing [4]. UWB signals spread, however, over very large bandwidths and overlap with narrowband services. As a consequence, regulatory bodies impose severe limitations on UWB power density in order to avoid interference provoked by UWB onto coexisting narrowband systems [5]. It is therefore necessary to take into account power considerations when designing UWB systems. Throughout this chapter we will show how the distance information made available by the UWB technology can be exploited to achieve low power levels and increase network lifetime in the long term, while providing an adequate network performance (in terms of data throughput) in the short term.

In the last few years, the increasing interest in applications based on the deployment of ad hoc networks triggered significant research efforts regarding the introduction of the energy-awareness concept in the design of medium access control (MAC) and routing protocols. Ad hoc networks are in fact considered as a viable solution for scenarios in which fixed infrastructure, and consequently unlimited power sources, are not available. In such scenarios, an efficient management of the limited power supply available in each terminal is a key element for achieving acceptable network lifetimes. This is particularly true for sensor networks, for which long battery duration is one of the basic requirements, given the typical size of such networks (up to thousands of terminals), as will be analyzed in Section 4.2.

Location information is another valuable way of achieving energy-awareness in ad hoc networks. In Section 4.3 we first review location-aware routing protocols

5 Spatial aspects of UWB

Thomas Kaiser, Jürgen Kunisch, Werner Sörgel, Christian Waldschmidt, Werner Wiesbeck, F. Argenti, T. Bianchi, L. Mucchi, L. S. Ronga, Alain Sibille, Sigmar Ries, Christiane Senger, W. Pam Siriwongpairat, Masoud Olfat, Weifeng Su, K. J. Ray Liu, and Feng Zheng

5.1. Introduction

The aim of this part is to discuss the spatial aspects of the UWB radio channel from various perspectives. First, in Section 5.2, *a model for the UWB radio channel* by J. Kunisch, a spatial model is presented based on measurement data that were obtained in office environments with line-of-sight, non-line-of-sight, and intermediate conditions. Basically, the goal was to arrive at expressions for the space-variant impulse response or, equivalently, for its space-variant transfer function such that impulse responses or transfer functions belonging to adjacent locations could be correlated properly. The distinguishing feature of the ultra-wideband indoor radio channel is that certain individual paths are recognizable and resolvable in the measurements. This is adequately reflected by the proposed spatial model. Moreover, the model covers also movements of the receiving or transmitting antennas on a small scale (several wavelengths). At the end, the relevant model equations are presented in a compact, algorithmic-like form.

Section 5.3, *UWB antenna arrays* by W. Sörgel et al., introduces state-of-the-art UWB antenna array concepts and their applications. Then, the transient radiation behaviors of UWB antenna arrays in the frequency and in the time domain are discussed by deriving the antenna arrays, transient responses and their quality measurements such as dispersion and ringing. The theoretical modeling is substantiated by experimental results, and then this section finishes with simulation results for a linear exponentially tapered slot antenna array (Vivaldi antennas) for time-domain beam steering.

In Section 5.4, *UWB polarization diversity* by F. Argenti et al., two transmitting antennas with orthogonal polarization are proposed in order to uniformly cover an indoor area. A single-antenna receiver results into a 2×1 MISO (multiple-input single-output) system so that space-time coding becomes applicable. The goal is to employ the polarization diversity in order to obtain a quality constant symbol detection while the receiver moves around within the covered area.

6 UWB ranging

Domenico Porcino, Jürgen Sachs, Rudolf Zetik, and Andy Ward

6.1. Introduction

Ultra wideband technology has been identified as one of the most promising techniques to enhance a mobile terminal or a sensor with accurate ranging and tracking capabilities.

In simple words, the basic idea behind most accurate positioning systems under development today is to determine the time that a radio wave takes to propagate from the transmitter to the receiver and then convert that measurement into a distance to enable the estimation of the *range* between the two devices. The initial estimate of this range distance is often called the pseudorange. By calculating the pseudorange from the querying device to multiple devices at known locations, (technique often called trilateration) it is possible to identify with high accuracy the position of a device itself (*positioning*). Finally, it is also possible to keep calculating these range estimates over time and follow the device over a given time window while it is moving inside the area covered by the ranging system (*tracking*).

The system just described only gives a simplistic view of what needs to be done to tackle a substantial number of technical challenges. Complex mathematical algorithms will be used in support of the ranging and tracking calculations. In fact, in the first place, it is necessary to be able to measure with a good accuracy a very low-power signal in any potential condition of operation (severe multipath included). This signal might additionally be composed of the intentional combination of multiple signals transmitted by a number of parallel antennas or nearby transmitters. Then it is necessary to distinguish inside the received signal a sufficient number of characteristics to allow an informed estimate of the distance between the receiver and the transmitter(s). Finally it might be necessary to combine the information from multiple (and possible redundant) sources to be able to provide the application layer with usable information on the position of the node and an estimate of the reliability of such information.

7 Regulation and standardization

Christian Politano, Walter Hirt, Nils Rinaldi, Gordana Drakul, Romeo Giuliano, and Franco Mazzenga

7.1. Introduction

Ultra-wideband (UWB) radio techniques have been extensively described in the previous chapters, and we emphasize in this section the most fundamental parameter that characterizes UWB radio, which is the capability of UWB devices to operate over a very large frequency range (several GHz bandwidth).

Since typical UWB radio may use spectrum already assigned to operative primary or secondary radio services, UWB radio devices—despite their extremely low transmission output power—may be a potential source of interference for incumbent radio services, and should provide the ability to coexist with legacy radio services.

In this section, we provide the reader with a comprehensive description of the worldwide UWB regulation and standardization framework under completion in order to elaborate novel and effective means of spectrum management based on coexistence mechanisms, instead of using conventional frequency-sharing mechanisms.

The first section, dedicated to regulation aspects, is introducing the UWB regulation framework elaborated under ITU-R to allow UWB devices, in particular UWB communication and positioning applications, to operate without requirement for individual right to use radio spectrum ("license-exempt") and on a "no protection, no harmful interference" basis. Then a detailed overview on the European regulation framework is provided to explain how prudent but constructive regulation rules are elaborated in this region.

The second section presents a UWB standardization overview in the USA and in Europe. It provides the global overview of IEEE working groups mandated for wireless personal area network (WPAN) including high-data-rate (IEEE802.15.3a) and low-data-rate (IEEE802.15.4a) communication applications, and introducing the most popular UWB technology candidates identified during the year 2004. The European standardization process is also presented in this section with an overview of the ETSI-TG31 task group mandated by the ECC for the definition

Index