

# Short-Range WIRELESS COMMUNICATIONS

Emerging Technologies and Applications



Editors

Rolf Kraemer and Marcos D. Katz

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# SHORT-RANGE WIRELESS COMMUNICATIONS

## EMERGING TECHNOLOGIES AND APPLICATIONS

Edited by

**Rolf Kraemer**

*IHP GmbH, Germany*

**Marcos D. Katz**

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# **SHORT-RANGE WIRELESS COMMUNICATIONS**

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# About the Editors

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# Foreword

I'm very pleased to be able to write the foreword and welcome you to the first in a new series of publications from Wiley of what we've called the WWRF Wireless Futures series. Each volume will address a key technology or concept that will play a major part in the wireless world of the future. WWRF (Wireless World Research Forum) was established in 2001 to bring together researchers from industry and universities to identify jointly the essential research questions and issues that the mobile and wireless research community needed to address. Now, with over 130 members from five continents and representing the most significant actors in the industry and the brightest stars in the academic firmament, we are reaching out to more research communities in developing markets and tackling key questions such as sustainability, efficient design and the future of networking. Membership of WWRF is available to all organizations that share our aims. Details can be found on our Web site <http://www.wireless-world-research.org>. To attain our vision of 7 billion people being served by 7 trillion devices by the year 2017, we need efficient and manageable short-range communication between the multitude of devices, both simple and sophisticated, that will fill our environment. The WWRF team on short-range communication (Working Group 5) have brought together all the key concepts, from those near to market to those still at the research stage, into a comprehensive and fascinating survey of the technologies that will be available to provide this. Their work continues, and if interested, you are strongly encouraged to get involved by contributing to, or attending, our meetings.

Dr. Nigel Jefferies  
*Vodafone Group R&D*  
*WWRF Chairman*

# Foreword

The Wireless World Research Forum has coined the vision of developing technology for ‘connecting 7 billion people with 7 trillion wireless devices by 2017’. The large amount of 1000 devices per human clearly is not going to be accounted for only by cellular technology, but a plurality of different wireless interfaces for a large set of different applications.

Cellular dominated the wireless industry over the past 20 years. However, in digital cellular’s initial years cordless telephony was seen to be the volume driver, with cellular being more a niche application. Approximately 10 years ago the wireless local area network (WLAN) popped up as an important method for broadband cordless local connectivity. And as we can see from what is happening today, it has started to prove to be the door opener for broadband cellular to become widespread. So we see short-range cordless telephony and WLAN having paved the way for making people accustomed to using untethered communications. As the advantages of its use become apparent in a local environment, users want to have connectivity everywhere and start using the same service in a cellular wide area network (WAN).

However, today short-range communications cannot only be seen as a market developer for cellular WAN technologies. These days we want to use high-speed wireless connectivity for other use cases than continued connectivity, as for example, for very fast synchronization of data between devices, or for multimedia entertainment distribution in homes, cars, busses, trains and airplanes.

Other examples of application fields are RFID and wireless payment systems, which are becoming more and more important in various countries these days.

But the main volume driver for reaching the 1000 wireless devices per human will most likely be sensor networks. We will network our heating, lighting, security, windows, our vehicles, the roads, the rivers – mainly anything which it makes sense to monitor and control. This will drive the wireless industry into new volume markets of great future.

We are currently only at the advent of wireless technology, in particular in the case of short-range wireless, starting to blossom in nearly any field of our life. This book therefore is a great overview of some of the hottest new developments. It is a perfect companion for technical and marketing managers wanting to get an overview of what is coming, as well as for R&D engineers who get plenty of hints on where to dwell in much more depth. I hope you will enjoy the reading and become an expert in short-range wireless, a frontier which is just starting to become explored!

Professor Gerhard P. Fettweis  
*TU Dresden, Vodafone Chair*



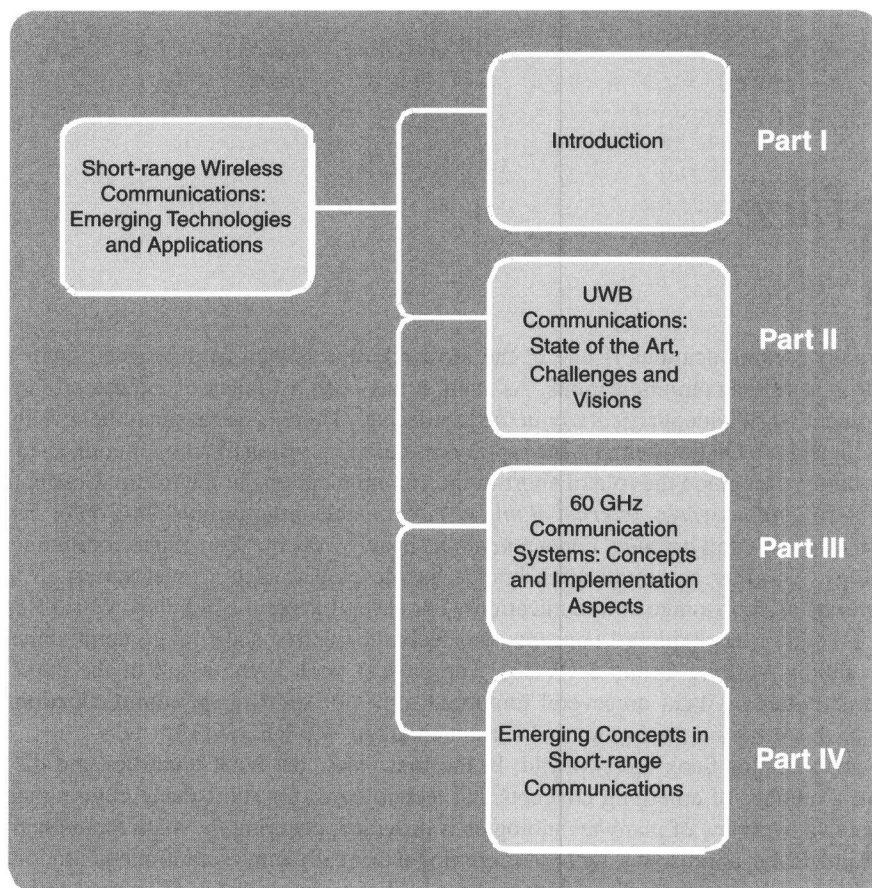
# Preface

Short-range communications is one of the most relevant as well as diversified fields of endeavour in wireless communications. As such, it has been a subject of intense research and development worldwide, particularly in the last decade. There is no reason to believe that this trend will decline. On the contrary, the rapidly crystallizing vision of a hyper-connected world will certainly strengthen the role of short-range communications in the future. Concepts such as *wireless social networks*, *Internet of things*, *car communications*, *home and office networking*, *wireless grids* and *personal communications* heavily rely on short-range communications technology. No other communication branch has developed such a great variety of technical solutions as short-range communications. For several years the Wireless World Research Forum (WWRF) has explored concepts and technologies for short-range communications, mostly within Working Group 5 (WG5). The present book is the result of the latest coordinated activities in WG5 on several important topics of short-range communications. The editors of this book are the former and current chairs of WWRF's WG5.

The goals of this book are two-fold. In the first place, the book identifies and discusses in detail a number of emerging concepts and technologies for short-range communications. An objective overview of many technologies is provided, covering the main theoretical background and design approaches, without forgetting the equally important implementation sides. The book serves also as a motivating source for further research and development activities in short-range. The limitations of current approaches and challenges of emerging concepts are discussed. Furthermore, new directions of research and development are identified, hopefully providing fresh ideas and influential research topics to the interested readers.

Short-range communications is an overly broad subject to be covered in reasonable depth by this single book. The topics discussed here were jointly chosen by the participating academic and industrial partners and therefore they represent areas of current interest with high potential to be widely exploited in the future. Thus, rather than covering all possible technologies in short-range, this book reflects in its contents a number of emerging concepts and associated technologies, identified over the last years by a worldwide research community participating in WWRF. Therefore, the contents are well representative of the current and future trends in the field. The book is organized in four independent parts, as shown in Figure 0.1. **Part I** (Introduction) contains an introductory chapter defining in general the scope of short-range communications, followed by a chapter discussing basic design rules for modern short-range communication systems.

**Part II** (UWB Communications: State of the Art, Challenges and Visions) presents a comprehensive and well balanced view of ultra-wideband (UWB) communications, one of the key enabling technologies for short-range communications. The 15 chapters of Part II introduce



**Figure 0.1** Organization of the book.

the most relevant aspects of advanced UWB transceiver design, including techniques such as pulse shaping, diversity, non-coherent detection, multiband modulation, synchronization, transmitter design, MIMO UWB and UWB channel modeling. In addition, UWB localization techniques are discussed. Moreover, implementation aspects are also taken into consideration, with subjects such as low-power UWB design and UWB A/D converters. UWB networking is also discussed, including UWB higher layers and UWB sensor networks for positioning and imaging, as well as coexistence aspects. Finally, regulation and standardization issues are also considered. The authors do not only discuss the state of the art in UWB, but also identify challenges and portray their visions on all these topics, aiming at motivating further research in these highly significant subjects.

**Part III** (60 GHz Communication Systems: Concepts and Implementation Aspects) is devoted to another rapidly-emerging short-range technology, millimeter-wave communications, particularly in the 60 GHz band. Seven chapters discuss fundamental theory, design techniques and implementation issues. 60 GHz systems are first approached from the regulation

and services perspective, giving the reader a wider view of the possibilities of using these techniques for implementing very-high-data-rate wireless personal area networks. The key underlying techniques for modeling and designing 60 GHz systems are discussed in detail, including channel propagation, baseband algorithms, modulation techniques and system architecture. System concepts and circuitry design for transceivers are discussed. Fundamental implementation aspects are also presented, such as front-end-friendly air interface design, full CMOS integration and system-in-a-package. Adaptive arrays for 60 GHz are also discussed, including assembly techniques and compensation on nonlinearities. This part is concluded with techniques for enhancing power amplifier utilization in millimeter-wave multicarrier systems.

**Part IV** (Emerging Concepts in Short-range Communications) introduces novel and very promising concepts in short-range communications. Part IV consists of two chapters. The first deals with UWB-over-fibre, a recently proposed approach combining wireless and optical fibre media to transmit ultra-wideband signals. Such a concept does not aim only at increasing communication performance; it also increases the range and opens up a new world of applications. The second chapter also addresses a new concept which is lately gaining significant attention from the industry and research community, namely visible light communications. As high-efficiency white-light emitting diodes are increasingly being used for indoor illumination purposes, their additional use for communications has been contemplated, creating an optical downlink by modulating the visible light with information-carrying data. The basic techniques, their limitations as well as challenges and opportunities, are discussed in this chapter.

Finally, questions, comments or any feedback on this book can be addressed directly to the editors at [kraemer@ihp-microelectronics.com](mailto:kraemer@ihp-microelectronics.com) and [marcos.katz@vtt.fi](mailto:marcos.katz@vtt.fi).

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Marcos D. Katz, *Oulu, Finland*

# Acknowledgements

This book is the result of coordinated efforts from leading researchers in Europe, America and Asia. The content of the book reflects the contributions and discussions in Working Group 5 (WG5) of WWRF (Short-range Communications) over the last years. We are grateful to the Steering Board and Vision Committee of WWRF for supporting this initiative.

The editors would like to thank the effort of each and every contributor to this book. Without the valuable contributions and enthusiastic participation of specialists around the globe this book would have never been possible. The authors of the chapters are (in alphabetical order): Antti Anttonen, Maria-Gabriella Di Benedetto, Yossef Ben Ezra, Troy Beukema, Olivier Bouchet, André Bourdoux, Steven Brebels, Isabelle Bucaille, Robert W. Brodersen, Geert Carchon, Chang-Soon Choi, Marcus Ehrig, Grahame Faulkner, Gerhard Fettweis, Gunter Fischer, Frank. H. P. Fitzek, Sinan Gezici, Eckhard Grass, Jelena Grubor, Valery Guillet, Frank Herzel, Ole Hirsch, Pertti Järvensivu, Thomas Kaiser, Timo Karttaavi, Markku Kiviranta, Antti Lamminen, Klaus-Dieter Langer, Kyungwoo Lee, Boris. I. Lembrikov, Hoa Le-Minh, Geert Leus, Kiattisak Maichalernnukul, Nadine Malhouroux-Gaffet, Srdjan Glisic, Aarne Mämmelä, Laurence B. Milstein, Andreas F. Molisch, Lorenzo Mucchi, Dominic O'Brien, Ian O'Donnell, Pascal Pagani, Maxim Piz, H. Vincent Poor, Jose A. Rabadan Borges, Walter De Raedt, Moshe Ran, Sebastien Randel, Juergen Sachs, Nuan Song, Jussi Säily, Christoph Scheytt, Klaus Schmalz, Bamrung Tau Sieskul, Isabelle Siaud, Claudio R. C. M. da Silva, Yaoming Sun, Reiner Thomä, Klaus Tittelbach-Helmrich, Anne-Marie Ulmer-Moll, Alberto Valdes-Garcia, A.-J. van der Veen, Antti Vimpäri, Takao Waho, Joachim Walewski, Piet Wambacq, Mike Wolf, Eun Tae Won, Sven Zeisberg, Lubin Zeng, Rudolf Zetik, Feng Zheng and Peter Zillmann. We thank you all for sharing with us your technical expertise, and for the professionalism shown during the editing process!

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We are deeply thankful for the forewords by Dr Nigel Jefferies, Chairman of WWRF, and Prof. Gerhard Fettweis, former chair of WG5. We appreciate their support and strong prospective views.

We thank Wiley for their encouragement and support during the edition process. Special thanks to Tiina Ruonamaa, Anna Smart and Sarah Tilley for their kindness, patience and flexibility.

Finally, we are grateful to our colleagues at IHP and VTT for their motivating discussions and for creating a truly pleasing working atmosphere.

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# **Part I**

## **Introduction**





# 1

## Introduction

Rolf Kraemer<sup>1</sup> and Marcos Katz<sup>2</sup>

<sup>1</sup>*IHP, Germany*

<sup>2</sup>*VTT, Finland*

Short-range communications systems characterize a wide range of scenarios, technologies and requirements. There is no formal definition of such systems though one can always classify short-range systems according to their typical reach or coverage. We define short-range communications as the systems providing wireless connectivity within a local sphere of interaction. Such a space corresponds to the first three levels of the multisphere model as discussed in the Book of Visions of the Wireless World Research Forum (WWRF) [1]. Figure 1.1 depicts the multisphere concept, highlighting the levels associated with short-range communications, namely Personal Area Network, Immediate Environment and Instant Partners [2–4]. Short-range systems involve transfer of information from millimeters to a few hundreds of meters. However, short-range communication systems are not only systems providing wireless connectivity in the immediate proximity, but in a broader perspective they also define technologies used to build service access in local areas. The WWRF envisions that by year 2017 there would be seven trillion wireless devices serving seven billion people. Certainly, the overwhelming majority of these devices will be short-range communication systems providing wireless connectivity to humans and machines.

Together with wide/metropolitan area cellular systems, short-range systems represent the two main developing directions in today's wireless communications scene. In terms of design rules and target capabilities, short-range systems have certain commonalities as well as marked differences from their counterparts, cellular systems. Maximizing the supported data throughput is quite often one of the main design targets for both types of wireless networks though a detailed comparison between them is not straightforward. Figure 1.2 shows the evolution of data rate support in cellular, metropolitan, Wireless Local Area Networks (WLAN) and very short-range systems. We can see that a steady increase in the supported throughput at a rate of approximately one order of magnitude every five years [5].