NANOTECHNOLOGIES FOR FUTURE MOBILE DEVICES

Tapani Ryhänen,
Mikko A. Uusitalo, Olli Ikkala
and Asta Kärkkäinen

CAMBRIDGE

Nanotechnologies for Future Mobile Devices

Edited by

TAPANI RYHÄNEN

Nokia Research Center, Cambridge

MIKKO A. UUSITALO

Nokia Research Center, Helsinki

OLLI IKKALA

Helsinki University of Technology

ASTA KÄRKKÄINEN

Nokia Research Center, Helsinki

CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore,
São Paulo, Delhi, Dubai, Tokyo

Cambridge University Press
The Edinburgh Building, Cambridge CB2 8RU, UK

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9780521112161

First published 2010

Printed in the United Kingdom at the University Press, Cambridge

A catalogue record for this publication is available from the British Library

ISBN 9780521112161 Hardback

Additional resources for this publication at www.cambridge.org/9780521112161

Nanotechnologies for Future Mobile Devices

Learn how nanotechnologies, mobile communication, and the Internet are related to each other, and explore the potential for nanotechnologies to transform future mobile and Internet communications and the value networks of future electronics manufacturing. Based on a research collaboration between Nokia, Helsinki University of Technology, and the University of Cambridge, here leading researchers and business analysts review the current state-of-the-art and future prospects for:

- Structural materials in mobile devices, including novel multifunctional materials, dirt-repellent, self-healing surface materials, and lightweight structural materials capable of adapting their shape.
- Portable energy storage using supercapacitor-battery hybrids based on new materials including carbon nanohorns and porous electrodes, fuel cell technologies, energy harvesting, and more efficient solar cells.
- Electronics and computing advances reaching beyond IC scaling limits, new computing approaches and architectures, embedded intelligence, and future memory technologies.
- Nanoscale transducers for mechanical, optical, and chemical sensing, nature's way of sensing and actuation, biomimetics in sensor signal processing, and nanoscale actuation.
- Nanoelectronics, for example based on graphene, to create ultrafast and adaptive electronics for future radio technologies, such as cognitive radio.
- Flat panel displays – how nanotechnologies can be used to achieve greater robustness, improved resolution, brightness and contrast, as well as mechanical flexibility.
- Open innovation in nanotechnology development, future manufacturing, and value networks.
- Commercialization of nanotechnologies.

Tapani Ryhänen is Laboratory Director of Nokia Research Center, heading Nokia's research laboratories in Cambridge and Lausanne. He is also responsible for Nokia's research collaboration with the University of Cambridge and the Ecole Polytechnique Fédérale de Lausanne (EPFL), and he is a Visiting Lecturer at the University of Cambridge.

Mikko A. Uusitalo is Principal Member of Research Staff at Nokia Research Center, Helsinki, where he has worked since 2000. He is a Founding Member of the Wireless World Research Forum (WWRF) and EUREKA CELTIC Initiative, and he is a Senior Member of the IEEE.

Olli Ikkala is Academy Professor of the Academy of Finland and Professor of Polymer Physics and Molecular Nanostructures at the Helsinki University of Technology. His current research interest is in developing concepts for functional nanomaterials based on macromolecules, synthetic polymers, and biomacromolecules.

Asta Kärkkäinen is Principal Scientist at Nokia Research Center, Helsinki, where she has worked since 1997. As a Research Manager of the Predictive Engineering Group, she has coordinated research on multidisciplinary design to enable optimal structural, thermal, acoustical, and chemical performance of future Nokia devices.

List of contributors

Gehan Amaratunga
University of Cambridge

Piers Andrew
Nokia Research Center

Marc Bailey
Nokia Research Center

Alan Colli
Nokia Research Center

Tom Crawley
Spinverse Ltd

Vladimir Ermolov
Nokia Research Center

Andrew Flewitt
University of Cambridge

Christian Gamrat
CEA-LIST

Markku Heino
Nokia Research Center

Olli Ikkala
Helsinki University of Technology

Laura Juvonen
Spinverse Ltd

Risto Kaunisto
Nokia Research Center

Jani Kivioja
Nokia Research Center

Pekka Koponen
Spinverse Ltd

Asta Kärkkäinen
Nokia Research Center

Finbarr Livesey
University of Cambridge

William Milne
University of Cambridge

Tim Minshall
University of Cambridge

Letizia Mortara
University of Cambridge

Johann Napp
University of Cambridge

Pirjo Pasanen
Nokia Research Center

Aarno Pärssinen
Nokia Research Center

Markku Rouvala
Nokia Research Center

Tapani Ryhänen
Nokia Research Center

Yongjiang Shi
University of Cambridge

Mikko A. Uusitalo
Nokia Research Center

Di Wei
Nokia Research Center

Yufeng Zhang
University of Cambridge

Preface

Human culture is simultaneously extending its capabilities to master the physical world at its molecular scale and to connect people, businesses, information, and things globally, locally, and pervasively in real time. Nanotechnologies, mobile communication, and the Internet have had a disruptive impact on our economies and everyday lives. Nanotechnologies enable us to use physical, chemical, and biological processes to create new functional materials, nanoscale components, and systems. This book explains how these technologies are related to each other, how nanotechnologies can be used to extend the use of mobile communication and the Internet, and how nanotechnologies may transform future manufacturing and value networks.

At the beginning of 2007, the University of Cambridge, Helsinki University of Technology, and Nokia Research Center established a collaboration in nanotechnology research according to open innovation principles. The target has been to develop concrete, tangible technologies for future mobile devices and also to explore nanotechnologies in order to understand their impact in the bigger picture. The collaboration is based on joint research teams and joint decision making. We believe that this is the proper way to build a solid foundation for future mobile communication technologies. The book is based on the visions of researchers from both academia and industry.

During the summer of 2007 a team of researchers and industrial designers from the University of Cambridge and Nokia created a new mobile device concept called Morph. The Morph concept was launched alongside the "Design and The Elastic Mind" exhibition at the Museum of Modern Art (MOMA) in New York, has been featured in several other exhibitions, won a prestigious *reddot* design concept award, and has had considerable publicity – especially in the Internet. To date, the concept has been viewed over three million times on YouTube. The story of Morph illustrates how nanotechnologies are linked to our everyday artifacts and our everyday lives. In our messages we have always emphasized realism and the responsible introduction of these new technologies to future products. We need to understand thoroughly both the opportunities and risks.

The public interest in the Morph concept may be related to the concreteness of everyday nanotechnology applications illustrating tangible, appealing consumer benefit and value. If the story of Morph was directed to a wider audience, this book is targeted at researchers and people creating future technology and business strategies in both industry and academia. However, we still emphasize the two issues, concreteness and consumer value. Our target has not been to write a comprehensive textbook or a review of nanotechnologies for future mobile devices but through selected examples to illustrate the impact on key mobile device technologies, manufacturing, value networks, innovation models, and ultimately on human societies. Our approach is also critical: sometimes the impact of a new technology is not straightforward and needs to be evaluated against competing technologies that may already be commercially available.

This is a vision statement of academic and industrial researchers working together in the spirit of open innovation. We hope that our book helps to promote stronger links between people working in different fields creating future concepts of mobile communication, Internet services, and nanotechnologies.

Contents

1 When everything is connected

T. Ryhänen, M. A. Uusitalo, and A. Kärkkäinen

1.1 Introduction

1.1.1 Mobile communication and the Internet

The Internet has created in only one decade a global information network that has become the platform for communication and delivering information, digital content and knowledge, enabling commercial transactions and advertising, creating virtual communities for cocreating and sharing their content, and for building various value adding digital services for consumers and businesses. The Internet phenomenon has been a complex development that has been influenced by several factors – an emerging culture that shares values that are brilliantly summarized by Manuel Castells [1]:

> The culture of the Internet is a culture made up of a technocratic belief in the progress of humans through technology, enacted by communities of hackers thriving on free and open technological creativity, embedded in virtual networks aimed at reinventing society, and materialized by money-driven entrepreneurs into the workings of the new economy.

The Internet can be characterized by four key elements: Internet technology and its standardization, open innovation based on various open source development tools and software, content and technology creation in various virtual communities around the Internet, and finally on business opportunities created by the Internet connectivity and access to the global information. The history and the origin of mobile communication are different and have been driven by the telecommunication operators and manufacturers. Digital mobile communication has focused on providing secure connectivity and guaranteed quality of voice and messaging services. The key driver has been connection, i.e., establishing a link between two persons. The global expansion of digital mobile phones and mobile network services has occurred in a short period of time, more or less in parallel with the Internet, during the last 10–15 years. Today there are roughly 3 billion mobile subscribers, and by 2010 nearly 90% of the global population will be able to access mobile voice and messaging services.

Mobile communication networks have also evolved from the original voice and text messaging services to complex data communication networks. The mobile phone

Nanotechnologies for Future Mobile Devices, eds. T. Ryhänen, M. A. Uusitalo, O. Ikkala, and A. Kärkkäinen. Published by Cambridge University Press.

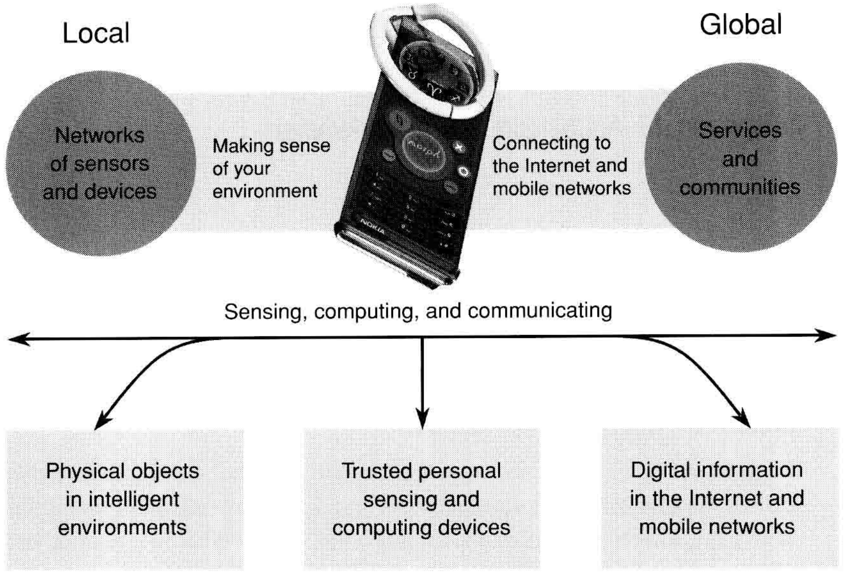

Figure 1.1 Mobile device as a gateway between local and global information and services.

has become a pocket-size mobile multimedia computer with various applications and capabilities to access networked services. The convergence of mobile communication and the Internet is one of the most signicant technology trends of our time with signicant social and economic impact. The mobile devices and networks are able to extend access to the Internet from homes and offices to every pocket and every situation in everyday life. Mobile phones outnumber personal computers by a factor of 5–10. In developing countries in particular, mobile phones are immensely important for accessing the Internet and its services as many people make their first connection to the Internet via a mobile phone.

It is very clear that the evolution of human society will be shaped by the global communication and information sharing networks. In this book we will discuss another important dimension that will bring the Internet and mobile communication even closer to human everyday life. We will discuss the new capabilities to master our interface to the physical world. The ability of human technologies to image, measure, and manipulate matter down to the molecular scale and to master the self-organizing structures of nature will extend our ability to invent new materials and manufacturing solutions, new energy, sensing, computing and communication technologies, and a deeper means to interact with living systems: our environment and our bodies. The aim of this book is to study these abilities in the context of the Internet and mobile communication and from the perspective of the era of the transformation of human society towards the new concept of seamless local and global interaction, illustrated in Figure 1.1.

1.1.2 Towards merging of physical and digital worlds

Mobile phones have already become an enabling platform for several digital services and applications. Mobile phones are now mobile computers with a wide range of multimedia functionality, e.g., imaging, navigation, music, content management, internet browsing, email, and time management. Increasingly they will have advanced multiaccess communication, information processing, multimedia, mass storage, and multimodal user interface capabilities.

Mobile phones are developing towards being trusted personal intelligent devices that have new fundamental capabilities, illustrated in Figure 1.1:

- to sense and interact with the local environment via embedded short-range radios, sensors, cameras, and audio functionality;
- to function both as servers for global and local internet services and as clients for global internet services;
- to serve as gateways that connect local information and global Internet-based services;
- to carry the digital identity of the user and to enable easy-to-use secure communication and controlled privacy in future smart spaces;
- to make sense of and learn from both the local context and the behavior of its user, and optimize its radio access, information transport, and device functionality accordingly.

Form factors and user interface concepts of mobile phones and computers will vary according to the usage scenario. The trend towards smaller and thinner structures as well as towards reliable transformable mechanics will continue. The desire to have curved, flexible, compliant, stretchable structures and more freedom for industrial design sets demanding requirements for displays, keyboards, antennas, batteries, electromagnetic shielding, and electronics integration technologies. Integrating electronics and user interface functions into structural components, such as covers then becomes a necessity.

The modular device architecture of mobile phones and computers consists of several functional subsystems that are connected together via very high-speed asynchronous serial interfaces [2, 3]. This modular approach enables the use of optimal technologies for particular functionalities, optimization of power consumption, and the modular development of device technologies and software. The same modular architecture can be extended from one device to a distributed system of devices that share the same key content, e.g., remote mass storage, display, or a printer.

A variety of new devices will be embedded in our intelligent surroundings. Ambient intelligence will gradually emerge from the enhanced standardized interoperability between different consumer electronics products and will extend into more distributed sensing, computing, storage, and communication solutions. The current communication-centric modularity will develop into content- and context-centric device virtualization.

The vision of ambient intelligence, in which computation and communication are always available and ready to serve the user in an intelligent way, requires mobile devices plus intelligence embedded in human environments: home, office, and public places. This results in a new platform that enables ubiquitous sensing, computing, and communication. The core requirements for this kind of ubiquitous ambient intelligence are that devices are autonomous and robust, that they can be deployed easily, and that they survive without explicit management or care. Mobility also implies limited size and restrictions on the power consumption. Seamless connectivity with other devices and fixed networks is a crucial enabler for ambient intelligence systems. This leads to requirements for increased data rates of the wireless links.

Intelligence, sensing, context awareness, and increased data rates require more memory and computing power, which together with the limitations of size lead to severe challenges in thermal management. It is not possible to accomplish the combination of all these requirements using current technologies. As we shall see in the rest of the book, nanotechnology could provide solutions for sensing, actuation, radio, embedding intelligence into the environment, power-efficient computing, memory, energy sources, human–machine interaction, materials, mechanics, manufacturing, and environmental issues.

1.2 Future devices, lifestyle, and design

1.2.1 Navigation in space and time

Early on the morning of Tuesday July 7, 2020, Professor Xi wakes up in her modern Kensington hotel room in London, still feeling tired after her long flight from Shanghai. Only a few years earlier she limited her traveling to the most important conferences and visiting lectureships. Her environmental ethics and the existence other means of communicating meant she preferred to stay mostly in her own university in Hangzhou. However, this invitation to give a series of lectures about Chinese innovation and environmental strategies to the MBA class of the London Business School gave her an opportunity to discuss both the history of innovation in China and its recent huge economical and technological advances.

After having breakfast Professor Xi decides to use the remaining hour before her meeting with Professor Williams to take a walk through a London park. It is a beautiful morning. Walking through the city, Professor Xi relies on her mobile device. Her thoughts return to her lectures. She opens her Morph device which shows her a map of the city, her location, and the route. She lifts the device, looks through it, and the device displays the street and the local information on services around her (see Figure 1.2). This is the modern equivalent of navigation, cartography, measuring of distances, and using a compass. All these ancient inventions of the Song dynasty are now encapsulated in this transformable piece of flexible and elastic material. She wraps the device around her wrist and walks on to her meeting, trusting in the instructions of her mobile personal device.

Professor Xi is moving through the streets of London that are depicted as a mixed experience of physical and virtual realities. At the same time she is able to find information about her environment that helps her to navigate towards her meeting. She is able to access local information about her surroundings – directly based on the local