Preface

INTRODUCTION

This IGI Global book, titled “Pervasive Computing and Communications Design and Deployment: Technologies, Trends, and Applications”, has a broad scope since it is intended to provide an overview on the general and interdisciplinary topic of pervasive computing and communications. The book is intended to serve as a reference point and textbook to computer science practitioners, students and researchers, as far as the design principles and relevant implementation techniques and technologies regarding pervasive computing are concerned. Particular aspects studied in this book include enabling factors, key characteristics, future trends, user adoption, privacy issues and impact of pervasive computing on Information and Communications Technology (ICT) and its associated social aspects.

Pervasive computing environments have attracted significant research interest and have found increased applicability in commercial settings, attributed to the fact that they provide seamless, customized and unobtrusive services over heterogeneous infrastructures and devices. Successful deployment of the pervasive computing paradigm is mainly based on the exploitation of the multitude of participating devices and associated data and their integrated presentation to the users in a usable and useful manner. The focal underlying principle of pervasive computing is user-centric provisioning of services and applications that are adaptive to user preferences and monitored conditions, namely the related context information, in order to consistently offer value-added and high-level services. The concept of pervasive computing further denotes that services and applications are available to users anywhere and anytime. Pervasive behavior is guaranteed by adapting systems based on monitored context information and accordingly guiding their re-configuration. Pervasive computing solutions should also be unobtrusive and transparent to the users, thus satisfying the vision of seamless interaction with computing and communication resources, as first introduced by Weiser in his seminal article for Scientific American in 1991. Research on pervasive and ubiquitous computing has been prolific over the past years, leading to a large number of corresponding software infrastructures and frameworks and an active worldwide research interest, as expressed by the numerous related University B.Sc. and M.Sc. programs, doctoral dissertations, national and international research grants and projects, etc.

In terms of communications, the proliferation of ubiquitous networking solutions experienced in the last few years in the context of ever popular pervasive application scenarios and the high rates of user adoption of wireless technologies lead us to believe that there is an established paradigm shift from traditional, infrastructure-based networking towards wireless, mobile, operator-free, infrastructure-less networking. The latter constitutes the foundation of existing and prospective pervasive applications. Pervasive environments built on principles of ubiquitous communications will soon therefore form the
basis of next generation networks. Due to the increasing availability of wireless technologies and the demand for mobility, pervasive networks that will be increasingly built on top of heterogeneous devices and networking standards will progressively face the need to mitigate the drawbacks that accordingly arise regarding scalability, volatility and topology instability. Novel trends in pervasive communications research to address such concerns include autonomic network management, re-configurable radio and networks, cognitive networks, use of utility-based functions and policies to manage networks autonomously and in a flexible and context-driven manner, to mention a few.

The cornerstone of enabling pervasive computing environments is the efficient and effective monitoring of the surrounding conditions and the discovery of the related generated information - called context information - that enables these environments to be adaptive. This monitoring is performed by means of sensors (or collections of them referred to as sensor networks) that can be either physical or virtual. The former interact with the actual environment and collect information about observed conditions, the status of users, etc., while the latter involve monitoring of computing systems and their properties. Context information comprises all aspects of the computing environment, e.g. device characteristics, available bandwidth, and of the users, e.g. user preferences, user history, mobility. As pervasive systems gain popularity the notion of the context of the user becomes increasingly important. Given the diversity of information sources, determining the context of a user is a complex issue that can be approached from different perspectives (technical, psychological, sociological, etc.). What needs to be clarified in relation to context is the fact that it cannot be strictly defined and bounded. It is the pervasive application or system and its use that actually defines what the corresponding context is. In other words, the intended usefulness and functionality of the pervasive application is tightly intertwined with its planned use. Nonetheless, most existing research frameworks and infrastructures for pervasive computing utilize context information in a rigid manner by tightly binding it with the prospective application use, limiting thus their potential extensibility. Therefore, the innovatory vision of pervasive computing, as seen within these infrastructures and platforms, will require users to acquire new applications and software, albeit the apparent contradiction with the promoted and anticipated notion of unobtrusiveness. Novel approaches to address this issue are thus required with the clear aim of making pervasive applications that will be used by users because they gain benefits from them and not merely as part of some research evaluation study.

Since the initial conception and introduction of the pervasive computing paradigm by Weiser in 1991 there has been a plethora of research work, both industrial and academic, with the aim of achieving the envisaged ubiquity, transparency, interoperability, usability, pervasiveness and user-friendliness of computing systems. While simplicity and seamless integration were the driving forces for this computing paradigm shift, the vast number of proposed related and enabling technologies, frameworks, models, standards, data formats, systems, etc. has significantly increased the perceived complexity and therefore acts as a hindering factor for its widespread deployment and adoption. Pervasive computing middleware approaches strive to alleviate these complexity issues, by building on principles of integration, abstraction, interoperability and cross-layer design. The publication of this book coincides with the 20 year anniversary of the pervasive computing realm, and in this respect it is important to examine existing approaches, in order to highlight the associated research problems and identify open issues and mainly look into future and innovative trends on middleware solutions for this domain.

From its inception, pervasive computing identified the need to make computing technologies easier, more useful and more productive for humans to use and to achieve this objective two enabling factors were pinpointed, namely transparency and unobtrusiveness. Users should not be tasked with the burden
of explicitly interacting with computing facilities, an activity which can prove to be stressful and time-consuming and even act as a barrier to the adoption of technologies. Pervasive computing solutions were introduced with the goal of removing this hindering barrier and empowering the users by giving them the option of implicit interaction with more advanced and intelligent, context-aware systems. Unfortunately, the majority of solutions to enable pervasive computing proposed in the related research and academic literature involves specific platforms and rigid architectures that are tightly bound with their target applications and services. This approach suffers from a lack of interoperability and from having to introduce new context-aware applications, thus limiting deployment in existing configurations. Additionally, users are often asked to explicitly configure and parameterize the systems that they utilize. Nevertheless, the notion of pervasive computing calls for solutions to be tailored in accordance to user needs and not vice versa. For computing systems to become pervasive, being transparent and unobtrusive, handling context monitoring and ubiquitous communications issues behind the scenes, is a major requirement. A key theme of the book is evaluation of pervasive computing systems and the study of factors that enable its adoption and acceptance by users. Despite being of paramount importance for the success of the pervasive computing paradigm, this aspect is by and large neglected in most current research work and the work presented in this book aims at partially filling this gap and also instigating further research in this direction.

The mere notion of pervasive and ubiquitous computing adheres to the “anybody, anywhere, anytime” concept of user access to information and services around the network. This concept, albeit facilitating user interactions with technology, also incorporates a significant number of security concerns. The use of wireless networking solutions alone increases the level of security threats and risk and requires more advanced solutions to be fashioned compared to traditional wired networking. Furthermore, pervasive computing implies the sharing of data and information amongst users of possibly different administrative domains and of no prior awareness of each other. Secure information management becomes therefore an absolute necessity in pervasive environments. Another security concern involves the adaptability of pervasive systems and their functionality in terms of dynamic and context-driven re-configuration, since both these aspects can be easily exploited by malicious users to adversely affect the operation of the system. Additionally, for any pervasive application to provide services customized to user needs and preferences, users should share personal information to that application to make it context-aware. A major problem that arises in this respect is that of privacy; users are on one hand cautious about sharing sensitive personal information and on the other hand on allowing computing systems to take decisions on their behalf. To address this concern, the benefits of pervasive applications should be better clarified to their users, so that their value also becomes clear. Any proposed solutions should cater for the diversity of protocols, services, applications, user preferences and capabilities of devices and promote effective and efficient countermeasures for all possible security threats. In doing so, security mechanisms should ensure that they do not limit the underlying principles of operation of pervasive computing, chiefly that of adaptive re-configuration based on widely available information exchange, but instead promote this paradigm by instilling to the users high levels of safety and trust towards pervasive environments and hence increase their acceptance and wide adoption. Security and privacy are topics that are reviewed in this book and relevant open issues, potential solutions and specific security mechanisms are highlighted.

It becomes therefore evident that pervasive computing is a widely dispersed research field in computer science. This interdisciplinary field of research involves a broad range of topics, such as networking and telecommunications, human-computer interactions (multimodal, tactile or haptic interfaces), wearable computing, sensor technologies, machine learning, artificial intelligence, user-centered design, data
interoperability, security, privacy, user evaluation, software engineering, service oriented architectures, etc. Researchers from all these fields strive to provide viable and usable solutions that reinforce the vision of pervasive computing and thus assist in reaching Weiser’s innovative conceptualization of future computing that calmly integrates itself with human activities. Aside to traditional approaches in tackling the open issues in this area, it is worth mentioning the introduction of visionary and possibly imaginative use of innovative studies that draw inspiration from biology (e.g. autonomic management, swarm intelligence), sociology (e.g. data gossiping, social networks), and nanotechnology (e.g. implantable miniature devices and sensors). Pervasive computing research builds on top of all these fields of studies and it is for this reason that we argue that all these viewpoints need to be holistically addressed when delving into the domain of pervasive computing and communications.

This book on “Pervasive Computing and Communications Design and Deployment: Technologies, Trends, and Applications” serves as a reference for current, original related research efforts and will hopefully pave the way towards more ground-breaking and pioneering future research in the direction of providing users with advanced, useful, usable and well-received pervasive applications and systems.

**ORGANIZATION AND STRUCTURE**

This book comprises 15 chapters, which were selected through a highly competitive process. At the first stage more than 45 short chapter proposals were examined and reviewed by the Editorial Advisory Board, leading to the acceptance of 32 full chapter proposals that underwent a double-blinded reviewing phase. The latter involved at least two reviewers per chapter proposal; the reviewers are internationally renowned researchers and practitioners in fields closely related to the specific book. The completion of the reviewing process yielded 15 greatly appreciated accepted chapters for publication (overall acceptance rate lower than 33%), the authors of which span across 10 countries and 20 research centers and universities.

The book is organized in 5 sections, namely **Context Awareness**, **Frameworks and Applications**, **Pervasive Communications**, **Security and Privacy** and **Evaluation and Social Implications**. Each of these sections is comprised of chapters that illustrate key concepts and technologies related to the focus of the corresponding section, as well as provide pointers for future research directions.

**Context Awareness**

The widely researched and of paramount important issue of accessing and retrieving data and context information in pervasive environments is the focus of the chapter by G. Vargas-Solar, N. Ibrahim, C. Collet, M. Adiba, J. M. Petit and T. Delot. This chapter is essentially a thorough state-of-the-art on querying issues in pervasive environments with a clear educational aim and can act as a reference for interested researchers. The authors propose a taxonomy that takes into account the mobility of the producers and the consumers of the data, its freshness and its pertinence, as well as whether the data has been produced in batch or it is a stream and how often the queries are being executed. The chapter reviews a big number of related works and classifies them according to the proposed taxonomy, while other taxonomies are also compared to the proposed one. Furthermore, general guidelines to take into account when designing querying solutions for pervasive systems are highlighted and suggestions on how to best satisfy the corresponding needs are also presented.
In the chapter by *I. Bisio, F. Lavagetto and M. Marchese* practical considerations on achieving context-awareness in real-world settings are examined and presented. This extremely interesting chapter follows a hands-on approach of describing practical examples of context aware service provisioning for smartphone appliances, with a special focus on digital signal processing techniques. The latter are utilized to support services such as audio processing (to identify the gender and the number of the speakers in a conversation and the matching of audio fragments), the location of a smartphone and the localization of its user (based on network signal strength) and user activity recognition (user movements recognition with the use of accelerometers). These three use cases of context awareness can form the basis for advanced, user-centric service provisioning, as envisaged by the pervasive computing paradigm. The authors illustrate the full extent of their experimental setup, from the prototypes/algorithms that have been used for evaluation are based on published work in the area to the measured results based on their experiments.

**Frameworks and Applications**

A software engineering framework to build adaptive, pervasive smart home applications is presented in the chapter by *J. Yu, P. Bourret, P. Lalanda and J. Bourcier*; the case-study discussed in their work involves a personal medical appointment reminder service, which incorporates information from various context sources in a rather novel way of producing adaptable service-oriented applications for smart environments. The applicability of this approach is focused on service-oriented applications and the adaptation occurs by means of dynamic service composition with the advanced feature of variation points as far as the service bindings are concerned. The latter points allow for the runtime binding of services according to semantics that express specific architectural decisions. The software engineering theory that this approach is founded on is that of architecture-centric dynamic service product lines and in this respect this is a very motivating chapter as it provides insight to dynamic software re-configuration approaches using the recently popular and widespread web technologies, such as Web Services. The merits of this approach are also presented, expressed by an evaluation study and a functional validation by means of several application scenarios.

The work by *O. Davidyuk, I. Sánchez Malara and J. Riekki* involves research on the composition of pervasive applications by means of the proposed CADEAU prototype system. The authors introduce the prototype, which allows to dynamically compose Web Services based applications in ubiquitous environments using 3 modes of user control, namely manual composition, semi-autonomic and fully autonomic. The architecture of CADEAU and its interaction design are clearly elaborated and a discussion on its usability and generally on end-user control in ubiquitous environments based on experiments over 30 participants is presented. This chapter is extremely interesting in that it can serve as a major contribution towards better user acceptance of future systems for the composition of ubiquitous applications.

The chapter by *P. Pace and G. Aloi* presents the design, development and deployment of a realistically applicable pervasive system targeted at providing user-centered, localized tourist-related information and associated multimedia and augmented reality contents. The aim of this system is to provide location-aware services to visitors of archaeological sites or other sorts of museums, namely location-based multimedia contents related to specific locations inside the visited area. A key aspect of the proposed system is user localization, which takes place by means of an advanced and powerful mechanism that relies on a combination of Wi-Fi, GPS and visual localization techniques. An assessment of the accuracy of the proposed integrated localization mechanism is presented, as well as details on the real-world
evaluation of the overall system. This chapter is an indicative representative of typical pervasive systems development research.

Some very attention-grabbing ideas from a currently active research project are reported in the chapter by M. Palviainen and A. Katasonov. This is a highly interesting chapter, reviewing specific outputs of the EU funded project SOFIA on a model and ontology-based development of smart space applications. The main contribution here is the proposal of a novel software engineering approach for the development of smart spaces applications, which takes into account ontologies and semantic models in order to facilitate the implementation of the latter applications. The use of ontologies in modern pervasive applications is considered by many researchers as essential, in order to be able to capture the wealth of knowledge regarding a particular domain and effectively express it in ways that computing systems can utilize it to become context-aware. The authors present a tool called Smart Modeler that enables the graphical composition of smart space applications and the subsequent automatic generation of the actual code. This is very useful when end-user programming is considered, an aspect of special importance in pervasive computing, since promoting the involvement of end-users is always desirable. This is an ongoing research and future directions are given, illustrating attractive contemporary areas of interest.

**Pervasive Communications**

Targeting the plethora of researchers striving to ameliorate pervasive communications, in terms of reconfiguration and autonomic management, the chapter by R. de O. Schmidt, R. Gomes, M. Johnsson, D. Sadok and J. Kelner presents a state-of-the-art survey of self-addressing approaches for autonomous networking systems. This work is extremely useful from an educational point of view, with a target audience of researchers and students who wish to commence research on the specific domain. After briefly introducing background information on the need for auto-configuration, and hence self-addressing, and discussing relevant design issues, the authors propose a classification of existing technologies. Based on the latter, specific systems are explained in detail, as indicative representatives of the various classes in the classification scheme, i.e. stateful, stateless and hybrid approaches. The chapter concludes by discussing open issues and latest trends in the area of addressing, such as the support for IPv6, and exposes possible future research directions.

In the chapter by A. Asgari the implementation and deployment of an architectural framework that enables the integration of wireless sensor networks in an overall enterprise building architecture are presented. The overall aim for this service oriented architecture is to create an appropriate building services environment that can maximize benefits, reduce the costs, be reliable and provide continuous availability, be scalable, stable and usable. Wireless sensor networks play an important role in this architecture and the particular considerations for this networking technology are taken into account in the description of this work. Of particular interest are the actual experiments in real buildings, where issues such as positioning of sensors, interference and accuracy are emerging. Scalability, extensibility and reliability that are extremely important in the wireless domain have been taken into account, while in parallel security issues are also reviewed. The author has thoroughly discussed the functionality tests, experimentations, and system-level evaluations and provided some environmental monitoring results to determine whether the overall objectives of the proposed architecture have been realized.

The work by H. Alasti constitutes an interesting chapter with clearly a significant amount of research efforts behind it. The topic is focused on energy conservation in wireless sensor networks and in particular how this can be achieved by means of a signal processing technique called level crossing
sampling. Emphasis on this chapter is placed on the latter technique, which is analyzed in detail from a theoretical perspective, while additionally simulation analysis and practical experiments of the energy gains are presented. This work is extremely interesting in terms of pervasive computing deployments, since the energy constraints of the participating devices are usually neglected. Approaches such as the one presented in this chapter could greatly benefit the wider adoption and long-term deployment of practical pervasive computing applications.

Security and Privacy

The chapter by F. Ortmeier discusses issues of dependability in the context of pervasive computing. An overall presentation of issues, such as functional correctness, safety, reliability, security and user trust, and possible ways to address them are given, with emphasis on the specific characteristics of pervasive computing systems. Of notable significance is a set of guidelines proposed by the author, on which system designers should target according to the nature of their systems. The notion of dependability is quite generic and encompasses many security and privacy aspects of pervasive systems, albeit at a higher level of abstraction. It is therefore more targeted at ICT practitioners delving into this particular field.

In the chapter by P. Belsis, C. Skourlas and S. Gritzalis the challenges hindering the efforts to disseminate medical information over wireless infrastructures in an accurate and secure manner are discussed. The authors report on their findings from international research projects and elaborate on an architecture that allows secure dissemination of electronic healthcare records. Security threats and their respective counter-measures are detailed, using an approach that is based on software agent technologies and enables query and authentication mechanisms in a user-transparent manner, in order to be consistent with the principles of pervasive computing. This chapter has a dual role in exposing the open issues in the extremely active research area of electronic health services, as well as in illustrating the security considerations that should be thoroughly addressed in every pervasive computing system.

Assuming a quite different stance compared to “traditional” IT papers that usually focus on research issues, experiments, description of systems, etc., the chapter by Al. Liotta and An. Liotta discusses privacy issues and the corresponding regulations (with a clear emphasis on EU legislation). Moreover, the related challenges in the context of pervasive systems are described providing input to further research efforts. Human-related aspects of pervasive computing are as important - if not more - as their technological counterparts, since one of the main challenges of pervasive systems is that of user adoption. Taking this into account, privacy is a very interesting and very much open issue in the domain of pervasive computing, due to the need for users to share an abundance of personal information. As such this chapter makes a great contribution to the book, since it assists in covering all related aspects of pervasive computing, ranging from design, implementation and deployment to social acceptance, security and privacy issues with these technologies.

Evaluation and Social Implications

In the chapter by D. Seng, C. Wilkin and L. Sugianto a methodological approach to analyzing user satisfaction with mobile portals is presented. The authors study the issue of user satisfaction with information systems in general and define their notion of what a mobile portal is and what user satisfaction reflects in that context. Based on the latter definitions, specific properties of mobile portals are presented, which are later used to derive user satisfaction factors, also utilizing existing literature in the area. The authors
validate their findings by means of a method that includes focus group discussions, which in this case established the validity of some of the findings and provided input for further user satisfaction factors. This particular case-study exposes the methodology used in consistently and accurately evaluating pervasive computing systems and can serve as a point of reference for researchers wishing to conduct similar evaluation studies.

A real-world deployment of a pervasive application is reported in the chapter by A. Komninos, B. MacDonald and P. Barrie. The focal point of the chapter justifies the high significance of this work, in that it presents a pervasive system from its design and implementation up until the actual deployment in a real environment. It is especially the latter part and the associated analysis, which forms the core of the work presented here, that distinguishes this work from the great number of existing research on pervasive systems, which usually is employed and tested in lab settings. Real-world evaluation and assessment of a pervasive system and explanations on why in this case it did not work out as anticipated render this chapter as very useful in terms of pervasive computing research. It is worth noticing that the focus is not so much on the technological aspects, rather on the societal ones.

The evaluation of a typical pervasive application in the aged care services domain is presented in the chapter by L. Sugianto, P. Smith, C. Wilkin and A. Ceglowski. The proposed evaluation solution involves a modified version of the traditional balanced scorecard approach used in information systems research, which takes into account both business strategy optimization and the user related aspects of the adoption of the pervasive technologies in the considered domain. One of the most remarkable findings in this article is the excellent analysis of the considered application area, based on both the practical deployment of a pervasive system in a health care environment in Australia, but also based on the thorough review of related work in the area.

**Prospective Audience**

The prospective audience of the “Pervasive Computing and Communications Design and Deployment: Technologies, Trends, and Applications” publication is mainly students in informatics and computer science that engage themselves with pervasive computing and communications. The book will serve primarily as a point of reference handbook to related technologies, applications and techniques, as well as an indicator of future and emerging trends to stimulate the interested readers. On a secondary basis, researchers will benefit from having such a reference handbook on their field, indicating the main achievements in the interdisciplinary domain of pervasive computing and the future trends and directions that could be potentially pursued.

**Impact and Contributions**

The target of this book is to serve as an educational handbook for students, practitioners and researchers in the field of pervasive computing and communications, whilst giving an insight of the corresponding future trends. The overall objective of the proposed publication is to serve as a reference point for anyone engaging with pervasive computing and communications from a technological, sociological or user-oriented perspective. Since the research stream of pervasive computing has been extremely active and prolific in terms of results and projects over the last few years, this publication targets at collecting the aforementioned research output and encompassing and organizing it in a comprehensive handbook.
The field is quite vast and is dispersed in many disciplines, hence the necessity for a handbook to collect and uniformly present all related aspects of pervasive computing and communications.

As far as the potential contribution to the field of research in pervasive computing is concerned, this publication is intended to have a twofold effect, namely:

- Provide a collective reference to existing research in the domain of pervasive computing and communications, taking into account its enabling factors (context awareness, autonomic management, ubiquitous communications, etc.), its applications, its usability and the corresponding user adoption.
- Future and emerging aspects of pervasive computing are reported in this book, through extensive reference to existing and ongoing research work by renowned groups of researchers and scientists.

It becomes therefore evident that this book will have an impact as being a reference for scholars wishing to engage in pervasive computing and communications related studies or research, bringing together the much dispersed material from the diversity of disciplines that jointly constitute this computing paradigm.

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