

Software Defined Radio

Architectures, Systems and Functions

Markus Dillinger

Siemens AG, Germany

Kambiz Madani

University of Westminster, United Kingdom

Nancy Alonistioti

University of Athens, Greece



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Software Defined Radio

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Preface

It is not uncommon for breakthrough concepts in wireless communications to take a considerable time to mature and gain momentum. In this respect, Software Defined Radio (SDR) is no exception, evolving very slowly from its military origin. J. Mitola first defined the area and also coined the term back in 1991 while Steinbrecher made initial investigations on the suitability of Software Radio in implementing multi-standard, flexible, smart base stations. As J. Mitola pointed out in his keynote speech at the 1st European Workshop on Software Radio in May 1997 when he referred to the slow start of SDR in the United States: *... it was not that the technology was not within reach, but rather the fact that commercial applications are quite cost sensitive*. A renewal of interest in the area occurred around 1996 driven by two events, namely the creation of the Modular Multifunction Information Transfer System (MMITS) Forum¹ in March 1996, and the launch of the first European research project on SDR in the context of the Advanced Communications Technologies and Services (ACTS) programme of European Union (EU) funded research and development (R&D).

One could say that the title of the first European research project in this area was prophetic as very becomingly it was entitled FIRST (Flexible Integrated Radio Systems Technology). Observing the rising interest by the international research community in what was still known at that time as S/W radio technologies, the European Commission (EC) organised the 1st European Workshop on Software Radio in May 1997. The objective of this event was twofold. First it provided an excellent opportunity to assess the interest of the European research community in this area while at the same time it aimed to provide valuable feedback that would assist in shaping future research activities in this area.

Without doubt the 1st European Workshop on Software Radio was a major success. The attendance of more than 170 researchers representing academic and industrial centres not only from Europe, clearly showed that European industry was ready to invest in this challenging new area. This was reflected in the 3rd Call for Proposals of the ACTS R&D programme which called for proposals on ‘... novel technological work in S/W Radio technologies’. As a result of this call, two projects were launched in this area: Smart Universal Beam-forming (SUNBEAM) and Software Radio Technology (SORT), the first addressing the integration of smart array antennas in a ‘software radio base station’, while the second investigated intermediate frequency (IF) and baseband issues.

The follow-up of the very successful 1997 workshop took place in the summer of 1998, this time jointly organised by the EC and the MMITS Forum. The objective of the 2nd

¹ In December 1998 the MMITS Forum decided to change its name to the SDR (Software Defined Radio) Forum.

Workshop on Software Radio was to foster the exchange of experience in the field and explicitly to promote a broader approach, extending beyond the terminal. However, the most significant moment in this chronology of events was probably March 1999 when the three ACTS research projects active in this area took upon themselves the initiative to organise the First European Colloquium on Reconfigurable Radio Systems and Networks (RRSN). For the first time in the context of that event a different system-oriented and all-encompassing perspective/approach to SDR was put forward that went beyond the mainstream thinking in the area that was viewed SDR as a technology ‘restricted’ to the baseband and radio frequency (RF) functions of a wireless terminal.

This system-oriented point of view of SDR became the starting point for the 1st Call for Proposals of the IST (Information Society Technologies) R&D programme launched early in 2000. As we are now approaching the end of the IST programme we can safely claim that the projects performing work in the area of SDR have made considerable progress in the direction of the above-mentioned vision. This is manifested by the large number of contributions made to the SDR Forum as well as ITU Working Party (WP) 8F, which is in charge of defining the technical, operational, and spectrum issues related to the future development of IMT-2000 and systems beyond IMT-2000. The purpose of this book is to provide an integrated view of the work performed in this area in the context of the IST programme. In this light, the network functions for managing flexible devices and network elements are presented without ignoring at the same time the users’ requirements and expectations from reconfigurable systems reflecting the system-oriented and all-encompassing perspective of the IST programme.

As we approach the end of the IST programme, this book acts as a repository of the ideas and concepts developed and investigated by the projects active in the area of RRSN. Without doubt reconfigurability will continue to play a central role in the overall system concept of wireless systems beyond 3G and also in the context of the 6th Framework Programme of EU funded R&D. In this context, the high-level objectives for the research work to be performed in the next four years could be summarised as follows:

- to achieve wide acceptance at standardisation level especially in what concerns network and service aspects; and
- to obtain to a clear understanding of the regulatory implications;

In this light, work in the context of the 6th Framework Programme will certainly build upon the sound basis established by the IST programme.

In conclusion, we wish to thank our colleagues who participated in the IST projects in the area of wireless communications for their commitment and co-operative spirit that is best reflected in this book. In particular, we thank the editors, Nancy Alonistioti, Markus Dillinger and Kambiz Madani, for their high quality contributions and Parbhu Patel for his enthusiasm and continuous support.

Brussels, 20 November, 2002
Dr Demosthenes Ikonomou
*European Commission
DG Information Society*

Abbreviations

2G	Second Generation Mobile Network
3GPP	Third Generation Partnership Project
AA	Alternating MAC Frame Utilisation Algorithm
AAA	Authentication, Authorisation and Accounting
AAAARCH	Authentication, Authorisation and Accounting ARCHitecture research group
ACH	Access feedback Channel
ADC	Analogue to Digital Converter
AF	Alternating Factor
AMM	Alternative Mode Monitoring
ANAI	Access Network Added Intelligence
ANFR	Council of the National Frequency Agency
AP	Access Point
APC	Access Point Controller
API	Application Programming Interface
ARIB	Association of Radio Industries and Business
ARQ	Automatic Repeat Request
AS	Application Server
ASIC	Application-specific Integrated Circuit
ASP	Application Services Provider
ATM	Asynchronous Transfer Mode
BCCH	Broadcast Control Channel
BCH	Broadcast Channel
BGCF	Breakout Gateway Control Function
BER	Bit Error Rate
BOV	Book of Vision
BPC	Baseband Processing Cells
BS	Base Station
BSC	Base Station Controller
BST	Base Station Transmitter
CAB	Charging, Accounting and Billing
CAC	Call Admission Control
CAMEL	Customised Applications for Mobile Network Enhanced Logic
CAP	CAMEL Application Part
CAST	Configurable Radio with Advanced Software Technology

CCF	Charging Collection Function
CDF	Cumulative Density Function
CDMA	Code Division Multiple Access
CDR	Charging Data Record
CEPT	Conference Européen des administration des Postes et des Télécommunications
CERP	Comité Européen des Régulateurs Postaux
CGF	Charging Gateway Function
CORBA	Common Object Request Broker Architecture
COPS	Common Open Policy Service protocol
COPS-PR	Common Open Policy protocol for Policy Provisioning
CPU	Central Processing Unit
CN	Core Network
CMM	Configuration Management Module
CSD	Circuit Switched Data
CSEL	Cell Selection
DCA	Dynamic Channel Allocation
DCH	Data Channel
DES	Discrete Event System
DHCP	Dynamic Host Configuration Protocol
DL	Downlink
DLC	Data Link Control
DLCC	DLC Connection
Drive	Dynamic Radio for IP-services in vehicular environments
DSA	Dynamic Spectrum Allocation
DSM	Distributed Shared Memory
DSP	Digital Signal Processor
DTX	Discontinues Transmission
DVB	Digital Video Broadcasting
DVB-T	Digital Video Broadcasting – Terrestrial
ECC	Electronic Communications Committee
ECTRA	European Committee for Regulatory Telecommunications Affairs
ED	Event Driven
EDGE	Enhanced Data Rate for GSM Evolution
ERC	European Radio Communications Committee
ETNO	European Telecommunications Network Operators' Association
ETO	European Telecommunication Office
ETSI	European Telecommunications Standards Institute
EXP	EXport Protocol
FA	False Alarm
FCA	Fixed Channel Allocation
FCC	Federal Communications Commission
FCCH	Frame Control Channel
FCFS	First Come First Serve
FCH	Frame Channel
FDD	Frequency Division Duplex

FEC	Forward Error Correction
FER	Frame Error Rate
FIFO	Fast in First Out
FPGA	Field Programmable Gate Array
FSA	Flexible Spectrum Allocation
FSM	Finite State Machine
FTAM	File Transfer, Access and Management
FTP	File Transfer Protocol
GGSN	Gateway GPRS Support Node
GIRC	Global Intelligent Reconfiguration Component
GMSC	Gateway Mobile Switching Centre
GoS	Grade of Service
GPS	Generic Process Sharing
GPRS	General Packet Radio Service
GRSF	Gateway Reconfiguration Support Function
GSM	Global System for Mobile Communications
GTP	Generic Tunnelling Protocol
GUI	Graphical User Interface
HAVi	Home Audio Video Interoperability
HCA	Hybrid Channel Allocation
HIPERLAN/2	High Performance Radio Local Area Network Type 2
HLR	Home Location Register
HO	Handover
HRM	Home Reconfiguration Manager
HSCSD	High Speed Circuit Switched Data
HSS	Home Subscriber Server
HTML	Hypertext Markup Language
HTTP	Hypertext Transfer Protocol
I-CSCF	Interrogating – Call Session Control Function
ID	Identification
IDL	Interface Definition Language
IEICE	Institute of Electronics, Information and Communications Engineers
IETF	Internet Engineering Task Force
IMEI	International Mobile Equipment Identity
IMS	IP Multimedia Subsystem
IMI	Initial Mode Identification
IMT-2000	International Mobile Telephony (3rd generation networks are referred as IMT-2000 within ITU)
INAP	Intelligent Network Application
I/O	Input/Output
IP	Internet Protocol
IRAC	Inter-Department Radio Advisory Committee
ISP	Internet Service Provider
IST	Information Society Technologies
IT	Information Technology
ITU	International Telecommunication Union

IU	Traffic User Interface
JAIN	Java APIs for Integrated Networks
JCC	Java Call Control
JCAC	Joint Call Admission Control
JOCAC	Joint Call Admission Control
JOLDC	Joint Load Control
JOSAC	Joint Session Admission Control
JOSCH	Joint Resource Scheduler
JRRM	Joint Radio Resource Management
JVM	Java Virtual Machine
LAN	Local Area Network
LCH	Long Transport Channel
LCS	Location Services
LCLS	Last Come Last Served
LFFS	Last Finished First Served
LHP	Last Hop Protocol
LIFO	Last in First Out
LIM	Location Information Manager
LODCL	Load Control
MAC	Medium Access Control
MAP	Mobile Application Part
mAh	milli Ampere hour
MD	Metering Device
MDC	Metering Devices Controller
MExE	Mobile Execution Environment
MGCF	Media Gateway Control Function
MIMM	Mode Identification and Monitoring Module
MM	Mobility Management
MMI	Man–Machine Interface
MNSM	Mode Negotiation and Switching Module
MO	Mobile Operator
MOBIVAS	Downloadable Mobile Value Added Services through Software Radio and Switching Integrated Platforms
MPHPT	Ministry of Public Management, Home Affairs, Posts and Telecommunications
MRFC	Multimedia Resource Function Controller
MSC	Mobile Switching Centre
MT	Mobile Terminal
MTS	Mobile Terminal Software
NTIA	National Telecommunications and Information Administration
NPRM	Notice of Proposed Rulemaking
OC	Occupied Carrier
OLAP	Online Analytical Processing
OMG	Object Management Group
ONS	Open Network Services
OSGi	Open Services Gateway initiative

OSM	Office of Spectrum Management
OSA	Open Service Access
OSI	Open Systems Interconnection
OTA	Over The Air
Overdrive	Over Dynamic multi Radio networks in Vehicular Environments
P2P	Peer to Peer
PCCPCH	Physical Common Control Channel
PCI	Personal Computer Interface
P-CSCF	Proxy-Call Session Control Function
PDA	Personal Digital Assistant
PDM	Packaging and Downloading Module
PDP	Policy Decision Point
PDU	Protocol Data Unit
PEP	Policy Enforcement Point
PHY	Physical Layer
PLC	Physical Layer Controller
PLMN	Public Land Mobile Network
PN	Pseudo Noise
PPP	Point-to-Point Protocol
PRM	Proxy Reconfigurable Manager
PS	Packet Switched
PW	Priority Weight
PV	Priority Vector
PVI	Priority Vector Information
QoS	Quality of Service
R&TTE	Radio Equipment and Telecommunications Terminal Equipment
RACH	Random Access Channel
RAN	Radio Access Network
ReSoA	Remote Socket Architecture
RAT	Radio Access Technology
RBB	Reconfigurable Baseband
RCH	Random Channel
RCM	Reconfiguration Manager
RDF	Resource Description Framework
RegTP	Regulierungsbehörde für Telekommunikation und Post
RESAC	Regular Traffic Session Admission Control
RF	Radio Frequency
RLC	Radio Link Control
RMM	Reconfigurable Baseband Management Module
RMSP	Reconfiguration Management and Service Provision Platform
RNC	Radio Network Controller
RR	Round Robin
RRM	Radio Resource Management
RRN	Reconfigurable Radio Network
RRSF	RAN Reconfiguration Support Function
RRU	Radio Resource Unit

RS	Resource Scheduling
RSC	Resource Controller
RSCPM	Reconfiguration Control and Service Provision Manager
RSF	Reconfiguration Support Functions
RT	Real Time
SAC	Session Admission Control
SADL	Service Architecture Definition Language
SCF	Service Capabilities Features
SCH	Short Transport Channel
S-CSCF	Serving – Call Session Control Function
SCOUT	Smart ser-Centric cOmmUnication environmenT
SDL	Specification and Description Language
SDR	Software Defined Radio
SDSAC	Software Download Session Admission Control
SDM	Service Deployment Manager
SDU	Service Data Unit
SF	Spreading Factor
SGSN	Service GPRS Support Node
SHO	Soft Handover
SIP	Session Initiation Protocol
SIR	Signal to Interference Ratio
SP&P	Spectrum Plans and Policies
SME	Small and Medium Enterprise
S-MSC	Mobile Switching Center Server
SMS	Short Message Service
SOAP	Simple Object Access
SRM	Serving Reconfiguration Manager
SRSF	Serving Reconfiguration Support Function
SS7	Signalling System No. 7
SSA	Static Spectrum Allocation
SWR	Software Radio
TAP	Transferred Account Procedure
TCAP	Transaction Capabilities Application Protocol
TCP	Transmission Control Protocol
TCAM	Telecommunications Conformity Assessment and Market Surveillance Committee
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TELEC	Telecom Engineering Centre
TGS	TCAM Group on SDR
TREST	Traffic Estimation
TRSCH	Traffic Scheduler
TRSF	Terminal Reconfiguration Support Function
TRUST	Transparently Reconfigurable Ubiquitous Terminal
TTI	Transmission Time Interval
UDCH	User Data Channel

UE	User Equipment
UIMM	User Interaction Management Module
UL	Uplink
UML	Unified Markup Language
UMTS	Universal Mobile Telecommunications System
UPnP	Universal Plug and Play
UTRA	UMTS Terrestrial Radio Access
UTRAN	Ultra Terrestrial Radio Access Network
VAS	Value-Added Service Provider
VASM	Value-Added Service Manager
VASP	Value-Added Service Provider
VC	Void Carrier
VHE	Virtual Home Environment
VoIP	Voice over IP
VSM	Viable Systems Model
WAP	Wireless Access Protocol
WCDMA	Wideband Code Division Multiple Access
WLAN	Wireless Local Area Network
WML	Wireless Markup Language
WSDL	Web Service Definition Language
WTB	Wireless Telecommunications Bureau
XML	Extensible Markup Language

Contributors' Biographies

Series and Book Editors

Markus Dillinger

Markus Dillinger received his Diplom-Ing. degree in telecommunications in 1990 from the University of Kaiserslautern, Germany. In 1991 he joined the Mobile Network Division at Siemens to develop call processing software for the GSM base stations. Later, he joined the system engineering division where he was responsible for the evaluation software for the Siemens Channel Sounder measurement equipment. In addition, he was responsible for the definition of the technical requirements and specification on the GSM base station line interfaces. From 1995 on he was working on the definition of the third mobile radio generation in the European research project FRAMES and in 1999 he was appointed Technical Manager of FRAMES. Since January 2000 he has been the project leader of the European research project TRUST and the follow-up project SCOUT for Software Radio. He has published many articles in the field of WCDMA and software radio.

Nancy Alonistioti

Nancy Alonistioti has a BSc degree and a PhD degree in Informatics and Telecommunications (University of Athens). She had been working for 7 years at the Institute of Informatics and Telecommunications of NCSR 'Demokritos' in the areas of protocol and service design and testing, mobile systems (UMTS), open architectures, CORBA, Intelligent Networks and SDR systems and networks. She has collaborated for one year as an expert at the Greek regulatory organisation and she is currently working as senior researcher and project manager in the Communication Networks Laboratory (University of Athens). She has participated in several national and European projects, (CTS, SS#7, ACTS RAINBOW, etc.) and is the Technical Manager of the IST-MOBIVAS project. She specialises in mobile communications, reconfigurable systems and networks, adaptable service engineering, formal specification and testing of communication protocol and services, test case design for conformance testing, and communications software engineering. Her current research includes: reconfigurability and adaptability management, protocol/software download and open architectures and platforms, CORBA, OSA/Parlay, JAIN, MEXE, etc.

Kambiz Madani

Kambiz Madani is the Technical Director of the Westminster Wideband research laboratory, University of Westminster, London, and has over 20 years of direct experience in leading many international industrial research and development projects for a variety of communication applications. With a PhD from King's College London (1979), he served as a senior principal design engineer at STC Telecommunications and as Technical Executive at ERA Technology, in charge of all research activities of the RF Technology Division, up until 1992. He then joined the University of Westminster and created the Westminster Wideband Research Laboratory, carrying out contract research in the communication systems area, and establishing the first specialist MSc Course in the UK in Mobile, Personal and Satellite Communications. He has been the technical leader for over 25 funded projects in the telecommunications field including the EC IST FP5 CAST Project. He has over 70 technical publications, and has been an active member of Technical Committees and sessions for many international conferences.

Contributors*Didier Bourse*

Didier Bourse (*didier.bourse@motorola.com*) currently holds the position of Team Leader with RASSEL Lab of Motorola Labs-CRM in Paris. He received his diploma degree in telecommunications in 1992 from ENSTBr (Ecole Nationale Supérieure des Télécommunications de Bretagne, France) and obtained his PhD degree in 1997 from IRCOM (Institut de Recherche en Communications Optiques et Micro-ondes, France). In 1997 he joined Thomson-CSF Communications and worked in the field of military tactical SDR. He was a member of the NATO FM³TR Technical Group. In 2000 he was the French Technical Manager of a French-German contract dedicated to a SDR Demonstrator realisation. He joined Motorola in January 2001 and was the Technical Manager of the European research project IST/TRUST for SDR. He is coordinating SDR activities within the Wireless World Research Forum (WWRF) and in 2002 edited the WWRF SDR White Paper 'Reconfigurable SDR Equipment and Supporting Networks – Reference Models and Architectures'.

Soodesh Buljore

Dr Soodesh Buljore is currently employed as Research Staff Engineer Senior, since 1998 at the European Communications Research Labs Paris, MOTOROLA LABS. He received his PhD degree, in Electrical Engineering, in 1996, from Ecole Doctorale Sciences pour l'Ingénieur, Ecole Centrale de Nantes. Between 1996 and 1998 he held a Post Doctoral fellowship at the Electrical and Computer Engineering at the University of California San Diego. He has been involved in the design and specifications of UMTS W-CDMA FDD, namely in new modulation and transmit diversity schemes. He is currently the Technical Manager of the IST project SCOUT and is also involved in the operations of other internal research programs. His research interests include, mobile radio communications systems, Software Definable Radio enabling technologies, 3rd Generation Air Interfaces and End to End Reconfigurable mobile radio systems for beyond 3G.

Genevieve Conaty

Genevieve Conaty is a human factors researcher at Motorola Labs in Basingstoke, England. Genevieve's work includes gathering information about user needs for future wireless applications, using a variety of methods such as consensual inquiry and group interviewing. Her work also involves the design, prototyping, and evaluation of new multimedia user interfaces. She completed her first degree in mathematical and computational science with a special interest in the history and philosophy of science at Stanford University. Her masters degree in human-computer interaction at Carnegie Mellon University included a team project about the design of wearable devices for teenagers. In addition, she worked on speech interfaces for information systems and games as part of the ICIE/RHINO Labs.

Lucas EliceGUI

Lucas EliceGUI joined Motorola Labs, Paris, in 1999 after receiving the Engineering Degree in Telecommunications from Ecole Nationale Supérieure d'Ingénieurs, Limoges. He initially carried out research in the field of radio systems performance analysis with an emphasis on radio resource management for UMTS. Then, he worked on flexible spectrum-sharing techniques and was responsible for the advanced spectrum-sharing activity within the TRUST project on reconfigurable radio. He is currently working in the Spectrum Engineering Centre (Motorola Labs) and is in charge of projects addressing spectrum engineering issues and radio systems coexistence analysis involving systems such as 2G, 3G and WLAN.

Michael Fahrmaier

Michael Fahrmaier received his Diplom-Inf. degree in Computer Science in 1998 from the University of Technology, Germany. Currently he is completing his PhD in Computer Science at the Munich University of Technology, Germany, while working as a researcher at the chair for Software and Systems Engineering of Prof. Dr Manfred Broy. His main research field is mobile and ubiquitous computing.

Jafar Faroughi-Esfahani

Jafar Faroughi-Esfahani (Motorola Ltd) works for Motorola's Wireless and Broadband Systems Group within the Semiconductor Products Sector. He obtained his BEng in Electronic Engineering from Southampton University and a Masters Degree in Software Engineering from Bournemouth University. He joined Motorola as a graduate in March 2000, doing research on software download and security issues for reconfigurable terminals for the IST-TRUST project. At present he is involved with the security team, researching the overall security architecture for SDR systems within the IST-SCOUT project. Furthermore, he is part of Motorola's 3G Systems Architecture team, focusing on subscriber platform software and security architecture.

Vangelis Gazis

Vangelis Gazis received his BSc in Computer Science from the Department of Informatics at the University of Athens, Athens, Greece, in 1995, his MSc in Computer Science

(Communication Systems and Networks) from the same department in 1998 and his MBA from the Athens University of Economics and Business in 2001. From 1995 until now he has been a research associate of the Communication Networks Laboratory (CNL) at the Department of Informatics in the field of mobile *ad hoc* networks and cellular systems (DECT, GSM/GPRS, UMTS). In parallel, he worked with a number of established companies in the Greek IT Services Sector (IBM Greece S.A., BYTE Computer, BP Oil International, etc.) as an IT networking consultant. He is currently pursuing a PhD in the Department of Informatics. His research interests include intelligent and reconfigurable service provision schemes and quality of service issues in 3G/4G mobile telecommunication networks.

David Grandblaise

David Grandblaise (david.grandblaise@motorola.com) received an MSc degree in Electrical Engineering with an emphasis in Telecommunications from ESME (Ecole Spéciale de Mécanique et d'Electricité, Paris) in 1998 and a Mastère degree with specialisation in mobile radio communications from ENST (Ecole Nationale Supérieure des Télécommunications, Paris) in 1999. In 2000 he joined Motorola Labs (European Communications Research Lab, Paris). After carrying out initial research activities on the physical and system aspects of UMTS transmit diversity techniques, his research activities have focused on system aspects of SDR since September 2000. David also contributes to SDR and reconfigurable radio research projects partly funded by the European Commission R&D program. He has contributed to the advanced spectrum-sharing techniques activity in the IST TRUST project. Currently he is responsible for the dynamic spectrum allocation and reconfigurability research activity in the IST OverDRiVE project. David's research interests cover SDR and reconfigurable radio with special emphasis on flexible spectrum management, spectrum and SDR regulation, radio resource management and wireless system performance analysis for dynamic multi-radio networks inter-operability.

Stoytcho Gultchev

Stoytcho Gultchev received a diploma degree in Electronics from EBTC Bulgaria in 1996. In 2000 he graduated as BEng in Information Systems Engineering from the University of Surrey, UK. In the same year, he started his PhD with the Mobile Communications Research Group in the Centre for Communication Systems Research (CCSR), the University of Surrey. His research is in the field of Software Reconfigurable Radio Technology looking into management and control architectures for reconfigurable terminals and networks. He works on the definition of Soft-Terminal Design Aspects contributing to the Mobile VCE work area on Software Based Systems.

Nikos Houssos

Nikos Houssos obtained his BSc degree in Informatics from the University of Athens in 1998 and his MSc (with distinction) in Telematics (Communications and Software) from the Department of Electronic and Electrical Engineering, University of Surrey, UK, in

1999. He is a staff member at the Communication Networks Laboratory of the University of Athens, working in the area of mobile service provision. He is involved in the projects MOBIVAS (including workpackage leadership) and PoLoS of the European Union IST framework. He is also currently pursuing a PhD at the Department of Informatics and Telecommunications, University of Athens. His current research interests relate to flexible value-added services provision in 3G/4G mobile communication networks and in particular to the design and implementation of service management and reconfiguration control platforms, intelligent service adaptation mechanisms, network reconfigurability and advanced business models. He has more than 15 publications in the above areas.

Péter Kacsuk

Péter Kacsuk is the Head of the Laboratory of the Parallel and Distributed Systems in the Computer and Automation Research Institute of the Hungarian Academy of Sciences. He received his MSc and doctorate degrees from the Technical University of Budapest in 1976 and 1984, respectively. He received the kandidat degree from the Hungarian Academy in 1989. He habilitated at the University of Vienna in 1997 where he is a private professor. He is a part-time, full professor at the University of Westminster, the Eotvos Lorand Science University of Budapest and the University of Miskolc. He served as visiting scientist or professor several times at various universities of Austria, England, Germany, Spain, Australia and Japan. He has published two books, two lecture notes and more than 140 scientific papers on cluster and grid tools, mobile computing, parallel computer architectures, parallel software engineering and parallel logic programming.

Tereska Karran

Tereska Karran is a Senior Lecturer in Information Systems at the University of Westminster where she teaches On Line Analytical processing and does research in complex information systems. She has contributed to several European Union projects.

Maria Koutsopoulou

Maria Koutsopoulou has received her diploma with distinction (ranked first in her class) in Electrical Engineering from the Demokritos University of Thrace, Greece, in 1996. In 1997 she received a fellowship for post-graduate studies from the Institute of Informatics and Telecommunications of the National Centre for Scientific Research 'Demokritos'. Since 1999 she has been a PhD candidate and member of the Communication Networks Laboratory at the Department of Informatics, University of Athens, working in the area of the software reconfigurable radio systems and networks and 3G mobile systems and data networks as well. Currently she works as a researcher in the IST project 'MOBIVAS' (Downloadable MOBILE Value-Added Services through Software Radio and Switching Integrated Platforms). Her research interests include design of open and flexible architectures and platforms, charging, billing and accounting issues for GPRS and UMTS systems and general IP networks.

David Lund

David Lund has worked as Senior R&D engineer with HW Communications Ltd for 5 years where his major responsibility guides the technical direction of their reconfigurable digital signal processing (RDSP) group. With a substantial track record in digital signal processing for communication applications, the group currently provides a major technical contribution to the 'Configurable Radio with Advanced Software Technologies' (CAST) project and the 'Two Dimensional Optical Storage' (TWODOS) project. CAST and TWODOS are both European Commission funded projects. CAST investigates the intelligent reconfiguration of SDR based mobile networks. TWODOS provides advanced optical storage research using SDR physical layer techniques for algorithm evaluation. David's recent PhD thesis entitled 'Reconfigurable Channel Coding for Future Communication Systems' tackles the problems associated with the practical implementation of information theoretical aspects of SDR.

Jijun Luo

Jijun Luo received his MEng degree from Shandong University, China, in 1999 and an MSc degree from Technische Universität München, Germany, in 2000. He joined Siemens in 2000 heading for his PhD affiliated to RWTH Aachen University, Germany. Until now he has published numerous technical papers mainly in the fields of information theory, mobile communication systems, SDR and radio resource management.

Mehul Mehta

Mehul Mehta graduated with a BEng (honours) degree in Electronic Engineering in 1994 and a PhD in 1998, both from the University of Southampton. His doctorate research focused on power control, air-interface and multiple access design considerations for non-geostationary satellite communication systems. In 1997 he joined Roke Manor Research Ltd (a Siemens Company) as a senior member of the technical staff. From 1997 to 2001 he worked on several research and development projects, including MAC layer design, wireless local loop link air-interface, 3G propagation modelling and planning tool development, UMTS link-level demonstrator and SDR. Since December 2001 he has been with Synad Technologies Ltd as a Principal DSP Engineer, where he is responsible for WLAN physical layer algorithm design and implementation, together with overall system performance analysis and modelling. Mehul's technical expertise includes algorithm design, DSP software development and system level analytical studies, all within the scope of wireless communications. He has authored several conference and journal papers. His current research interests include OFDM, CDMA and space-time signal processing. Mehul is a member of the IEEE and the IEE.

Stefano Micocci

Stefano Micocci was born in Pordenone in 1968. In 1993 he obtained his degree in Telecommunication Engineering from the Italian State University (Bologna). In 1995 he joined Italtel Central R&D. He has been active on multimedia and internet platforms. He participated in the MEDEA A109-2GMS project, where he has been active in the definition