INVITED PAPER *Special Section on Cognitive Radio and Spectrum Sharing Technology*

Introduction to IEEE P1900.4 Activities

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SUMMARY The Project Authorization Request (PAR) for the IEEE P1900.4 Working Group (WG), under the IEEE Standards Coordinating Committee 41 (SCC41) was approved in December 2006, leading to this WG being officially launched in February 2007 [1]. The scope of this standard is to devise a functional architecture comprising building blocks to enable coordinated network-device distributed decision making, with the goal of aiding the optimization of radio resource usage, including spectrum access control, in heterogeneous wireless access networks. This paper introduces the activities and work under progress in IEEE P1900.4, including its scope and purpose in Sects. 1 and 2, the reference usage scenarios where the standard would be applicable in Sect. 4, and its current system architecture in Sect. 5.

key words: *IEEE standardization, cognitive radio, network architecture, reconfiguration, heterogeneous radio access networks, distributed radio resource management*

1. Introduction

IEEE P1900 is a new standards series within the IEEE, established in 2005 jointly by the IEEE Communications Society and the IEEE Electromagnetic Compatibility Society. Its objective is to develop supporting standards dealing with new technologies and techniques being developed for next generation radio and advanced spectrum management. In March 2007, IEEE P1900 was reorganized as the Standards Coordination Committee 41 (SCC 41) [1].

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In February 2007, the IEEE P1900.4 WG [1] was launched under P1900, based on the P1900.B study group [3], and entitled "Architectural Building Blocks Enabling Network-Device Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Access Networks." This group aims at standardizing cognitive radio networks and is active in defining network architectures and functions for distributed decision making to optimize radio resource usage in heterogeneous wireless access networks [4], [5].

Four face-to-face meetings of P1900.4 in 2007 have thus far been held: February in Madrid, March in London, June in Paris, and July in Boulder, Colorado. Another two meetings in 2007 are planned: October in St Petersburg, and December in Berlin. As of 1st September 2007, this entity-based WG under the IEEE Corporate Forum [2] comprises 11 voting members of a range of different interest groups, including wireless operators, manufacturers, academia, and public organizations (see Sect. 6). Moreover, several companies are attending P1900.4 meetings as "observers," and are planning to join the group as active voting members in the near future.

The P1900.4 WG is focusing on infrastructured networks, e.g., comprising 2nd, 3rd, and 4th generation cellular radio access technologies, and 802 wireless standards of access networks. On top of this, work has been initiated to form a new task group in July 2007, in order to support infrastructureless systems, a typical example of which are moving access points/NodeBs within P1900.4. This is to ensure that the requirements for accommodating ad-hoc networks are recognized as the scoping of discussions proceed.

The WG currently defines three use cases: (i) "Dynamic Spectrum Allocation," allowing for the reallocation of spectrum bands dynamically among different systems, (ii) "Dynamic Spectrum Access," enabling opportunistic spectrum usage, and (iii) "Distributed Radio Resource Usage Optimization," enabling distributed decision making between network(s) and multi-mode terminals in the process of radio resource selection(s). Based on these use cases, system requirements, system architecture, enabling functions and their corresponding architecture, and an information model and interfaces between functions and procedures, are being discussed.

This paper introduces the activities within IEEE P1900.4, based on the latest discussions and contributions submitted thus far, as well as the baseline document of the standard which is in the process of refinement. The remainder of this paper is organized as follows. Section 2 presents the scope and purpose of the approved Project Authorisation Request for the WG. Section 3 discusses the main system assumptions and corresponding approaches which are further illustrating the scope, purpose and need for the project. Section 4 describes the three reference use cases currently discussed within the group. Section 5 presents the system architecture and related information to be exchanged. The main interfaces within the system architecture, and the corresponding information model which is under development, are briefly described in Sects. 5 and 6. Finally, Sect. 7 concludes and discusses the next steps. The current entity members of the IEEE P1900.4 WG are listed in Acknowledgements.

2. Scope and Purpose

This section outlines the scope and purpose defined in the PAR of IEEE P1900.4 [1].

2.1 Scope

The standard defines the building blocks comprising network resource managers, device resource managers and the information to be exchanged between the building blocks, for enabling coordinated network-device distributed decision making which will aid in the optimization of radio resource usage, including spectrum access control, in heterogeneous wireless access networks. The standard is limited to the architectural and functional definitions at a first stage. The corresponding protocols definition related to the information exchange will be addressed at a later stage.

2.2 Purpose

The purpose is to improve overall composite capacity and quality of service of wireless systems in a multiple Radio Access Technologies (RATs) environment, by defining an appropriate system architecture and protocols which will facilitate the optimization of radio resource usage, in particular, by exploiting information exchanged between network and mobile terminals, regardless of their support for multiple simultaneous links and dynamic spectrum access.

2.3 Need for the Standard

Multimode reconfigurable devices are increasingly being adopted within the wireless industry. The choice among various supported air interfaces on a single wireless device is already a reality today, with devices offering, for example, 2nd, 3rd generation cellular radio access technologies and 802 wireless standards. Further, devices and networks with dynamic spectrum access capabilities allowing the use of spectrum resource simultaneously among different systems are emerging (e.g. IEEE 802.22) and will be part of the radio eco-space. There is a need to define a standard addressing the overall system architecture and information exchange between the network and devices, which will allow the devices to optimally choose among the available radio resources and simultaneously use several of these resources such that the overall efficiency and capacity of the resulting composite network is improved.

3. P1900.4 System Assumptions and Approach

An example of a composite wireless network, managed by one or several operators in which P1900.4 system will operate, is depicted in Fig. 1. The key assumption is that devices (access points and end user terminals) operating in such composite network (network comprised of several radio access networks: RANs) have multi-mode capability with advanced features, such as support for simultaneous links on different radio access technologies and corresponding spectrum bands/channels.

The P1900.4 system will comprise a logical channel through which network and terminals communicate via their respective reconfiguration managers (Network Reconfiguration Manager: NRM and Terminal Reconfiguration Manager: TRM). This logical channel, depicted in dotted lines in Fig. 1) is called Radio Enabler (RE). The RE may be mapped onto one or several RANs used for data transmission (in-band channel) and/or onto one or several dedicated RANs (out-of-band channel).

4. Use Cases

Based on the assumptions in Sect. 3 and latest discussions in the working group during the Boulder meeting [7], three reference use cases[†] of the P1900.4 system have been defined. This section introduces them in detail. It should be

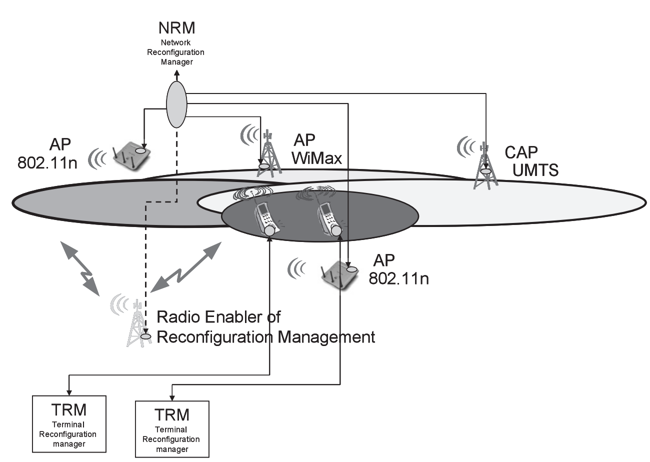

Fig. 1 Networks to operate P1900.4 system.

[†]By reference use cases, it is meant that system requirements and corresponding system architecture, functional requirements and corresponding functional architecture will be derived from these use cases.

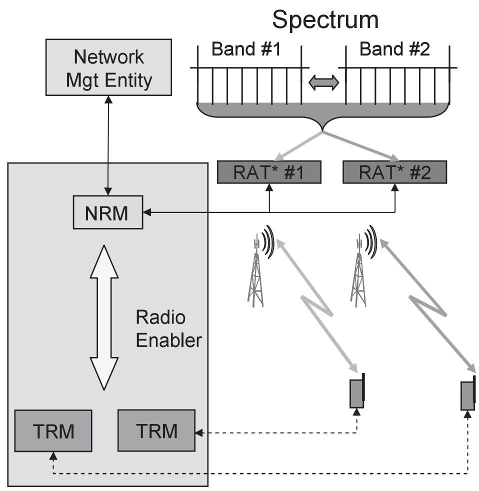

Fig. 2 Dynamic spectrum allocation.

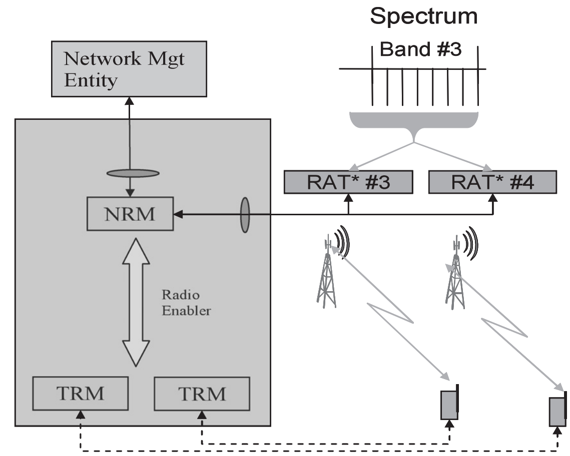

Fig. 3 Dynamic spectrum access.

noted that currently these three use cases are still being harmonized within the group and with P1900.1 WG for finalization [8]. Moreover, the corresponding functional requirements and architecture are being specified.

4.1 Dynamic Spectrum Allocation

It is assumed that the regulatory framework including spectrum usage rules is already in place and allows the Dynamic Spectrum Allocation, i.e. changes of frequency bands assignment for Radio Access Networks.

Dynamic Spectrum Allocation reconfigures network and terminal taking into account changes in the assigned purpose (e.g., operated RAT) for a spectrum band, as made by a composite network or a collaboration of networks as shown in Fig. 2. Such changes may occur on timescales on the order of few hours, and/or may be made at any time in reaction to a change in networking context such as network configuration, traffic patterns, QoS requirements, or radio measurements.

The Network Management entity, via the NRM, decides and performs Dynamic Spectrum Allocation in order to allow optimization of spectrum usage according to given criteria. This is achieved by changing the assignments of frequency bands of given Radio Access Technologies and Networks. End users' terminals, via TRMs, may make reconfiguration decisions taking into account the frequency assignment changes that occur on network side.

We present three example scenarios. The first one is refers to the appearance of a new carrier. When the new carrier operates 3G access, allocation of frequency band for 3G is rearranged and the new carrier uses a part of the original frequency band. The second one is an appearance of a carrier with different radio access technology (RAT). When a carrier for mobile broadband wireless access (802.16e) appears, it uses a frequency band previously used for 3G. For this purpose, reassignment of frequency to another radio is conducted. The third one is a carrier using two different types of radio in a coexistent manner. Network switches the usage of a spectrum band from mobile broadband wireless access (802.16e) to wireless LAN (802.11n), for instance, if a large number of wireless LAN terminals are suddenly close to the wireless LAN access point.

4.2 Dynamic Spectrum Access

In use of Dynamic Spectrum Access (Fig. 3), an end user terminal, which is operating as a secondary terminal in an unlicensed manner, opportunistically uses the incumbent radio's resources. This is allowed as long as the incumbent radio doesn't require the resources at that precise time and the end user terminal doesn't cause harmful interference to that radio. Decision making for this opportunistic spectrum access is performed jointly by the TRM and the NRM.

We present two example scenarios. One is an unlicensed secondary system, such as IEEE 802.22, accessing licensed TV spectrum bands that are not used. The other is an unlicensed wireless LANs, such as IEEE 802.11n, accessing licensed TV spectrum bands that are not used.

It is assumed that, in a heterogeneous radio environment where opportunistic spectrum access can be applied in several incumbents' bands, the decision making process supports the secondary end user terminal to select the most appropriate incumbents' bands meeting incumbents' and secondary end user terminals' requirements. P1900.4 will not develop any MAC or PHY mechanisms, but only the appropriate horizontal (between secondary terminals) and vertical (between incumbent and secondary systems) radio enablers to support secondary end user terminals operations within the incumbents' bands. The coordination needs to be inherent to the P1900.4 Radio Enabler information/constraints/protocols according to the coarse time granularity requirements. Any fine-grained time requirements of radio resources scheduling is left to the device to manage via the distributed decision making and its inherent dynamic access, PHY & MAC.

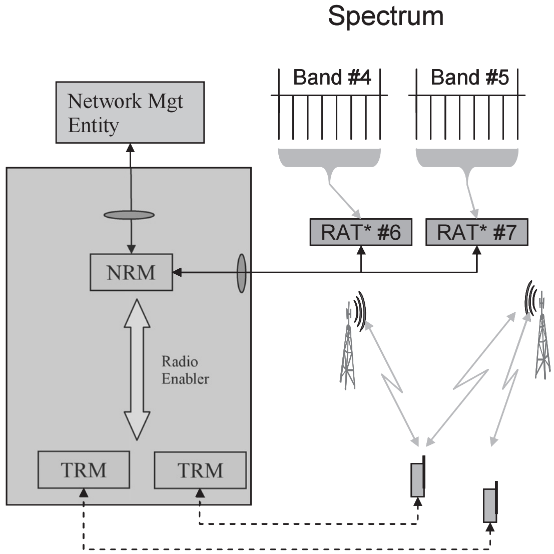

Fig. 4 Distributed radio resource usage optimization.

4.3 Distributed Radio Resource Usage Optimization

The Distributed Radio Resource Usage Optimization case may be seen as a two level optimization procedure, distributed between the network and the terminals as shown in Fig. 4.

In the first level, the NRM in the network side, through its Policy Provision module, derives policies and evaluates them in order to meet an objective pertinent to network resource optimization.

In the second level, end user terminals optimize their use of RATs/bands/etc. by selecting in turn the optimal one (or the optimal combination of RATs/bands/etc.) in the sense it yields the maximal throughput, offers the required quality of service (QoS), or satisfies user's preferences, etc. Their choices also have to be compliant with policies derived in the first level, which are broadcast (or multicast) by the NRM. The optimization in the terminal level is done by respecting a "time constraint" provided by the network.

We assume that user terminals are capable of simultaneously connecting to several Radio Access Technologies.

One of the example scenarios for this use case is optimization triggered by a network context change. When a network context changes, for example, in case of users' connection and disconnection, end user terminals select better resource usage strategy, thus adapting to the change independently of the network side.

Another example for this use case is mobile scenario when a mobile terminal selects appropriate access point and corresponding RAT based on network policy and context information.

5. System Architecture

Figure 5 shows the current architecture of P1900.4 system

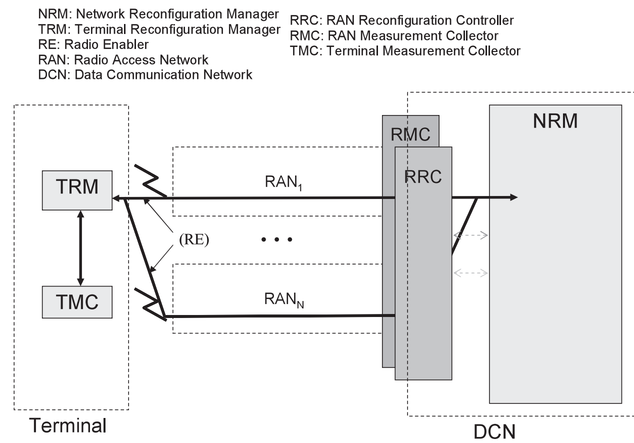

Fig. 5 System architecture.

Table 1 Information to be exchanged via interfaces.

Interface between NRM and TRM		
	From NRM to TRM	reconfiguration policies context information
	From TRM to NRM	user's preferences context information
Interface between NRM and RRC		
	From NRM to RRC	RAN reconfiguration requests
	From RRC and NRM	RAN configuration status information
Interface between NRM and RMC		
	From NRM to RMC	RANs-related measurement requests
	From RMC to NRM	RANs-related measurement results
Interface between TRM and TMC		
	From TRM to TMC	terminal-related measurement requests
	From TMC to TRM	terminal-related measurement results

[7], [9], which is subject to further development & refinement, The purpose is to mainly to define the overall design of P1900.4 system, or the relation of various building blocks and corresponding interfaces which are associated with the functional architecture and introduce reference points and illustrative mapping to selected standards (such as 3GPP, IEEE802.11x, IEEE802.16x, etc.). This is important to be able to implement the standard in a real context, in a later stage.

The Network Reconfiguration Manager (NRM) is the entity that manages the Composite Wireless Network and terminals for network-terminal-distributed optimization of spectrum usage. Terminal Reconfiguration Manager (TRM) is the entity that manages the terminal for network-terminal-distributed optimization of spectrum usage within the framework defined by the NRM and in a manner consistent with users' preferences and available context information. RAN Reconfiguration Controller (RRC) is the entity that enables NRM reconfiguration of RANs. RAN Measurement Collector (RMC) is the entity that provides RAN-related measurement results to NRM. Terminal Measurement Collector (TMC) is the entity that collects terminal-related measurement results and provides them to TRM.

Interfaces are defined between NRM and TRM, NRM and RRC, NRM and RMC, and TRM and TMC. Table 1 shows type of information to be exchanged via each interface.

The representation of data to be exchanged through the interfaces will be defined in the standard. This representation will encapsulate various types of information elements associated with P1900.4 services that realize reconfigurations of network and terminal, and management of radio resources.

6. Information Model and Representation

Based on the functional requirements for the different interfaces (at the system level-between main P1900.4 building blocks and corresponding entities- and at the functional level-between main P1900.4 functions within the building blocks and corresponding sub-functions for the realization of reference use cases in Sect. 4.), the corresponding information model and representation will be defined. The main purpose of an information model is to model managed objects at a conceptual level, independent of any specific implementations or protocols used to transport the data. The information model captures various types of information elements necessary to realize network and terminal reconfigurations and radio resource management within the P1900.4 framework. Table 1 shows the type of information under consideration in the P1900.4 baseline draft. At the time of writing this article, the group is considering using a hierarchical class model to abstract various common aspects associated with communication such as link, channel, cost, security and quality of service. This approach would permit re-use of data representations for multiple radio access technologies and will be particularly useful for fulfilling the requirements of efficient capability query, exchange and notification mechanisms. A more detailed information model between the main functions and sub-fuctions is under development, whilst requirements for this have already been drafted [7].

7. Conclusion

This paper has discussed ongoing activities within the IEEE P1900.4 WG, also outlining its purpose, scope, the need for the project, system assumptions, reference use cases, and the system architecture based on the latest discussions. The WG is currently in the process of finalizing its baseline document, wherein the requirements, system architecture, baseline functional architecture, and information model will be clearly scoped. This will lead in the ensuing stage to the precise detailing of the specification [10]. The group is open to new members wishing to join the entity working group. The expected date for initial Sponsor Ballot is July 2008.

Acknowledgements

The Chair of P1900.4 WG would like to acknowledge the very active contributions of our current voting members: Alcatel-Lucent, BAE Systems, Motorola, France Telecom R&D, Intel Corporation, King's College London, the National Institute of Information and Communications Technology, Toshiba Research Europe Limited, the University of Athens, the University Polytechnic of Catalunya, and the University of Pireaus. The chair would also like to acknowledge the contributions of the current observers who attend WG meetings on a regular basis: Hitachi, ISB, KDDI R&D, L-3 Communications, Mitsubishi, and Thales.

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Soodesh Buljore was born in 1967 in Mauritius. He conducted his university studies in France, after obtaining his Higher School Certificate from Cambridge UK. He received his Ph.D., in 1995 from Ecole Doctorale Science pour Ingénieur de Nantes, in France. He subsequently held in 1996–1997 a Postdoctoral Fellowship at University of California San Diego, where he conducted research on Advanced Antenna Diversity Techniques for CDMA air interfaces. He joined Motorola Research labs in France in 1998 where he designed advanced modulation techniques, including transmit-receive diversity and contributed to the 3GPP UMTS air interface specifications and in later stage MIMO technologies for 3GPP UMTS subsequent releases. During 2002–2004, he held the Technical Manager position of the IST-SCOUT project. He also co-launched the IST-E2R project in 2004. In his latest activities, he has project manage several internal Motorola Labs research projects for the Design and Proof of Concept of an end-to-end system for over the air Device Diagnostics, Management and Radio Access Network optimisation. Since 2006, he is the Chairman of the IEEE P1900.4 WG, sponsored by the SCC41. He holds several patents and published several papers in various technical journals and conferences in the domain of wireless communications systems. He is a member of IEEE and IEEE-SA.

Markus Muck was born in Ulm, Germany in 1972. He received the Diplom- Ingenieur degree in Electrical Engineering of the University of Stuttgart, Germany and the ingénieur diplomé degree of the Ecole Nationale Supérieure des Télécommunications (ENST) of Paris, France, both in 1999. Since then, he is a staff member of Motorola Labs in Paris, France. He currently acts as the Technical Manager of the IST-E2R Integrated Research Project and participates actively to Standardization in the area of Cognitive Radio and Wireless Communications (IEEE802.11n, etc.); he played a key role in the creation of the IEEE P1900.4 standard. He is a member of IEEE.

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Oliver Holland obtained his B.Sc. degree in Physics and Music (with First Class Honours) from Cardiff University, UK. He obtained his Ph.D. in Telecommunications from King's College, University of London, UK. Oliver is currently working on behalf of King's College as a Research Associate within the Virtual Centre of Excellence in Mobile & Personal Communications (Mobile VCE). Oliver maintains a number of research interests, including cross-layer optimisation, terminal and network reconfiguration, cognitive radio, radio resource optimisation in heterogeneous networks, network traffic modelling, end-to-end and network-assisted software download methodologies, and end-to-end and network-assisted reliable multicast among others. Oliver has published over 40 papers in various technical journals and conferences, and has acted as a TPC member of a number of conferences.

Andrej Mihailovic received a Ph.D. degree in mobility management for IP networks, M.Sc. degree in dynamic channel allocation for cellular telecommunications systems and B.Eng. degree in electronic engineering, all from King's College London. His research interests include development of various types of IP networks B3G/4G, routing, mobility management, multihoming, multicast, QoS, architectural, business and service aspects of IP connectivity, reconfigurability and network management. His work experience in King's College includes work in numerous projects either in individual work for industry or as a member of project consortiums. Currently he is working in E2R II European Union collaborative project. His list of publications includes around 30 international publications and 3 filed patents.

Kostas A. Tsagkaris was born in Lamia, Greece, in 1976. He received his diploma (in 2000) and his Ph.D. degree (in 2004) from the School of Electrical Engineering and Computer Science of the National Technical University of Athens (NTUA). His Ph.D. thesis was awarded in 2005 "Ericsson's awards of excellence in Telecommunications." He has been involved in many international and national research projects, especially working on the area of wireless networks resource management and optimization. He has been involved in many international and national research projects, especially working on the area of wireless networks resource management and optimization. Since January 2004 he is working as a senior research engineer at the Department of Technology Education and Digital Systems of the University of Piraeus. From September 2005 he is an adjunct Lecturer in the undergraduate and postgraduate programs of the Department of Technology Education and Digital Systems of the University of Piraeus. His current interests are in the design and management of wireless reconfigurable networks, optimization algorithms, learning techniques and software engineering. Dr. Tsagkaris is a member of IEEE, ACM and a member of the Technical Chamber of Greece.

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Gary Clemo is research manager for software, protocol and terminal architecture activities within the Toshiba Telecommunications Research Laboratory in Bristol. He graduated from Cardiff University in 1995 with a degree in computer systems. In 1996 he joined the Networks and Protocols group of the Centre for Communications Research at the University of Bristol. His work as a research assistant spanned many areas, including Intelligent Networks, distributed transactional processing network management. In 1999 he joined the Telecommunications Research Laboratory of Toshiba Research Europe Ltd, where his work centred of uses of middleware technology to facilitate IT/telecoms convergence towards the goal of flexible, reconfigurable networks and terminals. He holds a Ph.D. in the area of the uses of service discovery to support reconfigurable terminals.

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Klaus Nolte was born in 1950. In 1973 he received his diploma in mathematics at the Moscow State University. From 1973 until 1987 he worked as an assistant professor at the Technical University in Merseburg (former GDR). In 1980 he received his Ph.D. for work on optimization of dynamic processes. From 1987 until 1990 he worked in the Institute for Informatics of the GDR Academy of Science in East Berlin. Since 1990 he works for Alcatel (now Alcatel-Lucent). Until 1997 he worked as team leader in development teams for TMN systems. Since 1997 he is in charge of the Alcatel Research Department in Berlin. He worked on SW architecture and technology for 3GPP UMTS systems, especially signalling processing in base stations. Later this work has been extended onto the HSxPA design. Since 2005 he works for the EU project E2R, developing Proof of Concept solutions and standard contributions. He also works in other national funded projects.

Makis Stamatelatos received the B.Sc. and M.Sc. degrees from the National and Kapodistrian University of Athens, Greece. Participation in the EU-funded research projects includes E^2R I & II working in the area of end-to-end reconfigurability and beyond 3 G mobile communication networks. He is also involved as Designated Representative at the IEEE P1900.4 WG. He is currently pursuing a Ph.D. in Profile and Knowledge Management in OO context.