FP6 E²R Programme Achievements and Impact

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ABSTRACT

This paper presents an overview of the different research areas investigated in the Integrated Project End-to-End Reconfigurability (E²R II) project, highlighting the main achievements of the consortium. E²R II is a partly funded project that follows the successful achievements of the first phase and addresses the core of the Strategic Objective "Mobile and Wireless Systems and Platforms Beyond 3G" within the 6th Framework Programme. E²R II is concentrating on most promising solutions identified in E²R I and will assess any emerging new technologies, while in parallel evolving towards an integrated framework. The E²R II project aims to realise the full benefits of the diversity within the radio eco-space, composed of wide range of systems such as cellular, fixed, wireless local area and broadcast.

1. INTRODUCTION

The key objective of the E²R project is to devise, develop, trial and showcase architectural designs for reconfigurable devices and supporting system functions in order to offer an extensive set of operational choices to the users, application and service providers, operators, manufacturers and regulators in the context of heterogeneous systems [1]. This project has brought together the key players in the domain of Reconfigurability, Software Defined Radio and Cognitive Radio who have a precise understanding of the state-of-the-art from their involvement in various projects and technical bodies. These previous initiatives have motivated the E²R I project, but today's ambitions, especially after the first phase, are to go further to the end-to-end aspect and reconfigurability support aiming at providing the seamless experience to users, enabled by the end-to-end reconfigurability.

In this direction, End-to-End reconfigurable systems will provide common platforms and associated execution environments for multiple air interfaces, protocols and applications, which will yield to scalable and reconfigurable infrastructure that are capable of optimising resource usage through the use of cognition based methods; reconfigurability will also extend network and equipment capabilities and versatility by flexibly modifying software settings of the equipment involved. These capabilities will benefit users through facilitating provision of the required services wherever and whenever needed at an affordable cost. Furthermore, E²R II proposes to facilitate niche markets and provide users with specialised services via customised solutions that are open, flexible and programmable at all layers. E²R II is seen by many actors of the wireless industry as a core technology to enable the full potential of Beyond 3G systems. It has the potential to revolutionise wireless communications, just as the PC has revolutionised computing.The subsequent sections of this paper present an overview of the E²R II system approach and highlight the key technical achievements of the project; finally, some conclusion remarks are also drawn.

2. E²R II SYSTEM APPROACH

The E²R II main scientific and technological objectives that will allow achieving the end-to-end reconfigurability vision are the following:

- Develop and evaluate an overall reconfigurability system architecture and deployment concept considering actors (e.g. user, operators, vendors, service providers, etc.) requirements and views, as well as regulatory perspectives, and to overcome the current technological barriers by furthering the state-of-the-art of the key enabling technologies,
- Design and validate the system concepts, theoretical tools and technical solutions that will enable the use of reconfigurable equipments and networks for seamless and transparent communication across collaborative heterogeneous environments (multiple domains, multiple operators),
- Design and validate the system mechanisms necessary to facilitate resource aware and efficient access and use of radio resources, by employing cognition based mechanisms for optimised access to resources in the heterogeneous radio environment,
- Devise governing principles in a way that benefits all the players within the radio eco-system by exploiting the diverse nature of the heterogeneous radio environment,
- Develop a evolutionary proof-of-concept framework to validate and prototype the developed concepts and mechanisms,
- Exploit, disseminate and standardise the E²R technologies, providing a forum by actively contributing to the relevant standardisation bodies, industry fora and regulatory bodies.

In order to devise and implement the radio eco-system with the envisaged functionalities, a smart and well-structured approach is required. Hence, the approach that was adopted by the E2R I consortium is followed, proposing three main components:

- <u>E²R System Research, Business Path and Technology Roadmaps</u> is focusing towards compelling scenarios and user requirements of the radio eco-system, building on FP5 projects and other ongoing WWI integrated projects via cross issues instrument. In addition, the corresponding roadmap of the identified key enabling technologies within an overall architecture, re-enforced by regulatory rules, is helping to set out a clear path of End-to-End reconfigurability within the radio eco-space,

- Core Technology Research, Design and Proof of Concept constituted another area of work within the E²R charter. Research work is encompassing the technologies needed to transform embedded flexibility into end-to-end reconfigurability, while finding the right balance between integrated versus distributed approaches. This would yield the optimisation of resources (spectrum, radio, network and equipment) and reconfiguration functions (discovery, negotiations, control and triggering),
- E^2R Proof of Concept Evolutionary Platform is enabling the validation of the charter of E²R as a whole, thus esttablishing the proof of concept of the overall system within the radio eco-space.

3. E^2R II ACHIEVEMENTS

This section highlights the main technical achievements of the E^2R II project in various research domains.

3.1 Unified Business Model - UBM

In a business perspective, E^2R-II research activities include elaboration on business models for reconfigurability by identifying business roles and relationships and building the overall business model framework for end-to-end reconfigurable systems. The business analysis has been carried out facilitated by the Business System Architecture Process (BSAP)[2]. The Unified Business Model (UBM) (Figure 1) stands for the main outcome of E^2R-II business research activities. UBM has been elaborated in a number of Business Modeling Workshops [3] that have been organized by E^2R-II; it also integrates business modeling and regulatory perspective as well as interactions with the WWI partner projects. More details about the UBM can be found at [4]. The UBM framework has been applied to a number of use cases that have been distilled from the Unified Scenario [5]; such uses cases present different contexts of use of reconfigurable networks and terminals.

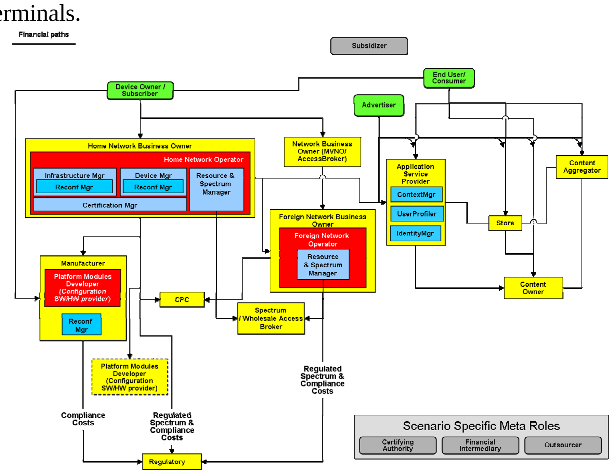

Figure 1: The Unified Business Model – UBM

The business challenges posed by the use cases are diverging. The business model analysis include a UBM instantiation omitting the roles not represented in the use case and specifying them where needed. This emerges the possible roles combinations, the transaction flows as well as possible bottlenecks. As a further step, the use case story and the UBM instantiation are taken together to formulate the different business challenges they present; where possible these are grouped together in categories.

3.2 Responsibility Chain Concept

In this context the E^2R Responsibility Chain concept is identifying a number of sensitive areas that include third parties' software, access of a device to a RAT, and the whole responsibility for a reconfiguration procedure. A set of actors has been identified as well. The responsibility allocation has been evolved based on two models, namely the horizontal (reconfigurations can be authorised by different actors and software only needs a declaration of standard compliance) and the vertical (reconfiguration can be carried out only by the equipment manufacturer who also provides software and hardware platforms.

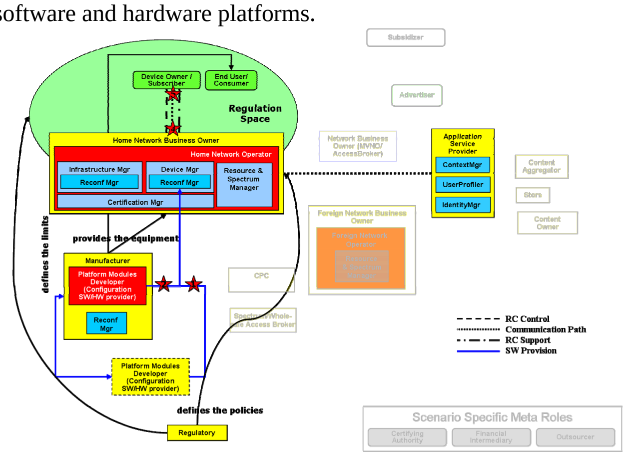

Figure 2: The Responsibility Chain

The responsibility chain concept is linked to the business modeling framework (Figure 2) a harmonized approach has been elaborated that maps the regulatory actors to the UBM roles. Additionally, an instantiation of the UBM depicts the sensitive areas and allocated responsibilities.

3.3 End-to-End Reconfigurability System Architecture Including Mapping onto Existing/Emerging Standards

The E^2R II system architecture definition is defined as illustrated in Figure 3 and its mapping to current network architectures, aiming at an optimal split of reconfiguration intelligence and functionalities between cognitive network elements and reconfigurable end-user equipment [6]. The proposal is in particular taking requirements into account which are assuring an efficient system operation based on distributed decision making and autonomics principles. A corresponding mapping of the E^2R architecture onto the different existing standards is performed in order to illustrate the specific implication of existing technologies and to improve them with reconfigurability and autonomics concepts in mind.

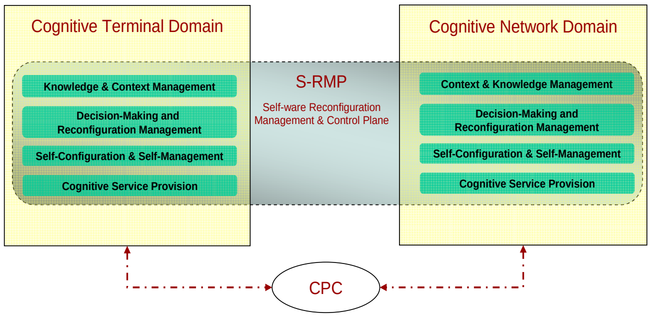

Figure 3: E²R II System Architecture

In other words, investigations have been pursued with respect to enhancements to the standards and adaptations to the E^2R Architecture, to see how some standards can be modified to capture reconfigurability and cognition needs. Four kinds of standards are considered by E^2R II: the 3GPP UMTS (release 7) which includes UMA, i-WLAN, the Evolved 3GPP, the OMA DM and the WLAN. All of the investigations are built upon an evolved Reconfiguration-Management-Plane (RMP) model.

3.4 Self-ware Reconfiguration Management Plane (S-RMP)

The RMP model consists of the so-called Selfware Reconfiguration Plane (SRP), which views the entire element as an autonomous entity, offering cross-layer user, control, and management reconfiguration capabilities [6] . In addition, three generic OA&M areas form the so-called Reconfiguration Layer Management, which handles parameters and resources per connectivity, access, and upper protocol layers. The SRP caters for: i) Autonomic decision-making and policy-based orchestration of reconfiguration operations, including negotiation control and mobility management between access systems, ii) Discovery of reconfiguration services and service provisioning leveraging cognition techniques, iii) Administration of the software-download process, iv) Self-configuration and self-management, and v) Retrieval and processing of contextual information, including spectrum and radio resource optimization.

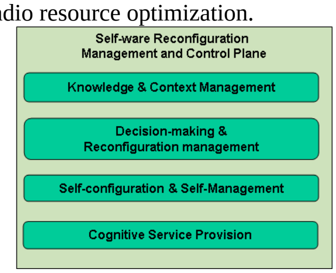

Figure 4: E²R II Self-ware Reconfiguration Management Plane

3.5 FSM / DSA Solution Proposal from Technical, Regulatory and Business Perspectives

Architecture of a dynamic spectrum management system in a reconfigurable environment is proposed. In this context, the spectrum market, which originates from the definition of a spectrum pool, is a logical spot where some Radio Access Networks (RANs) could trade spectrum with others [7]. In the spectrum market, if some RAN can satisfy its own service requirements and has spare spectrum as well, it can lease its extra spectrum out to maximize spectrum efficiency and its profits.

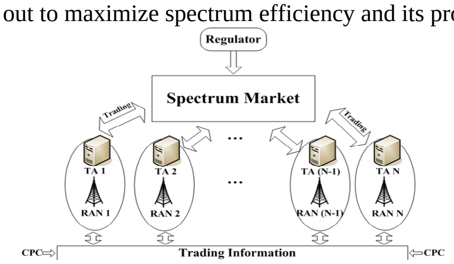

Figure 5:E²R II BDSM Architecture in Reconfigurable Systems.

3.6 Functional Architecture (FA) and Inherent Solutions for Optimized Exploitation of Spectrum and Radio Resources

E^2R concepts, algorithm and mechanisms are integrated using a functional architecture (FA) to formulate a novel reconfigurability enabled radio resource efficiency scheme, which will be then used to investigate into enabling technologies and theoretical tools for reconfigurable systems to enhance the overall radio resource usage efficiency [8]. This outcome provides the integration roadmap of the new scheme indicating what will be developed and its stages. Additionally, this includes an abstract description of the proposed algorithms, mechanisms and simulation tools from the reconfigurability perspective.

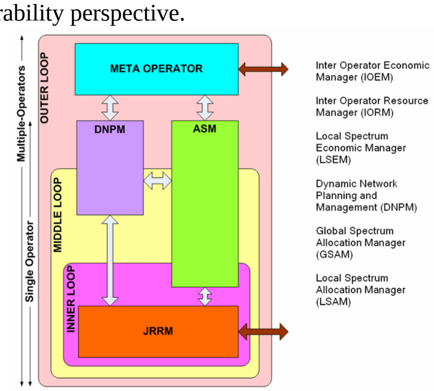

Figure 6: E²R II Functional Architecture

On the other hand, if some RAN lack of spectrum owing to increasing services, it becomes a consumer of the spectrum market. In order to make more profits and satisfy as many service demands as possible, the RAN will try to rent spectrum from others as the basic cost to proceed with its service provisioning. Once there is a market, there should be policies to regulate the operation of trading behaviours. A regulator is a repository of these principles, e.g. trading regulations, hostile competition bans and so on. Furthermore, the RANs should know some necessary trading information, for instance, which RANs possess available spectrum, what frequencies is spare spectrum, as a common channel, an out-band Cognitive Pilot Channel can be applied to inform diverse RANs the trading information.

The actions of the FA can be categorized with respect to time into three loops. The outer loop is the slowest action field and describes the framework for the actions of the middle loop. The same relation holds between the middle and the inner loop. The loop concept is a hierarchical scheme in time. It states only that the inner loop acts fastest and the middle loop faster than the outer one, e.g., the outer loop changes its behaviour every day, the middle loop in the range of minutes and the inner loop approximately every second. Besides the time categorization, the actions can be summarized in different responsibility functionalities: Meta Operator, Dynamic Network Planning and Management (DNPM), Advanced Spectrum Management (ASM) and Joint Radio Resource Management (JRRM).

3.7 Dynamic Network Planning and Management (DNPM).

The DNPM related efforts cover management functionality for reconfigurable network segments. Optimisation schemes enabling the computation of optimal reconfigurations, given the conditions and constraints encountered in the network segment. Input consists of context information (e.g., traffic demand, mobility, conditions, interference conditions, etc.), profile information (e.g., related to users, terminals, applications, network elements), policies (e.g., related to network operators) [9]. Output consists of the element reconfigurations (e.g., RAT and spectrum selection per transceiver, traffic allocation to RATs and networks, QoS allocation to user classes). A phased optimisation strategy is followed, relying on greedy techniques (augmented in some appropriate cases by exhaustive search of solution space). Bayesian networks are used for part of the context sensing. Work consists in formal problem definition, solution, algorithm development, result collection, demonstration, dissemination. Identification of future steps for more closely addressing emerging network technologies (e.g., mesh) and for integrating cognitive network concepts.

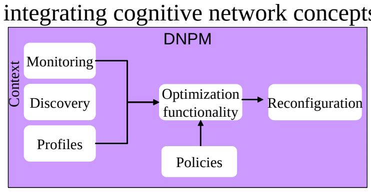

Figure 7: High Level Analysis of DNPM Functionality

3.8. Advanced Spectrum Management (ASM)

Suite of techniques for advanced spectrum management in the context of reconfigurable, flexible and cognitive infrastructures. It includes a number of sub modules such as Global Spectrum Allocation Manager (GSAM), Local Spectrum Economic Management (LSEM) and local Spectrum Allocation Manager (LSAM) to support spectrum management functionalities[8]. The techniques enable optimised Dynamic Spectrum Assignment, depending on the actual (temporal and regional) deployment scenario. The technologies are applicable for both, optimisation on the radio access network side, achieved through base station level, or inter operator level negotiations. While on the access side optimisation between terminals/user and base stations take place. In E^2R phase 1, the cell-by-cell dynamic spectrum allocation (DSA) scheme is extensively investigated with two radio access technologies (RAT) sharing a single frequency band based on the assumption that a single operator providing a digital video broadcasting and a cellular service. As the next evolutionary step, the cell-by-cell scheme was extended for three radio access technologies of different frequency bands with additional networks including non-infrastructure and mixed networks. An efficient meta-heuristic technique, named genetic algorithm, was developed. Genetic algorithms are search procedures, modelled on Darwinian theories of natural selection and survival of the fittest. The method shows excellent performance in solving mathematically hard problems including the dynamic spectrum allocation. Moreover, the optimisation strategies investigated include auction based mechanisms, which allow the negotiation of spectrum and radio resources, based on market driven incentives. The auction types investigated support dynamic allocations in medium and long term allocation scenarios. While auctions cater for relatively small numbers of participants, the second range of approaches discussed allows large numbers of terminals to partake in the optimisation process. These are based on the principles of cognitive radio; thereby the actual cognition should be a collaborative system function rather than in each individual terminal. Optimisation mechanisms include game theory and swarm intelligence approaches.

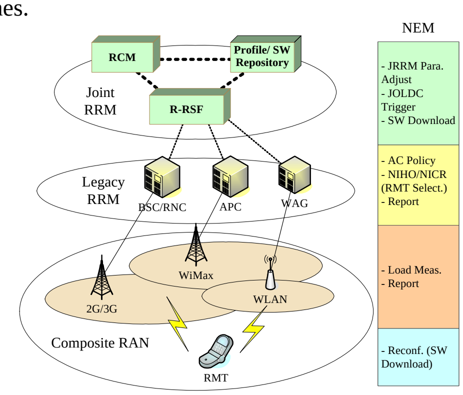

Figure 8: E^2R II Reconfigurable System Architecture for JOLDC

3.9 Joint Radio Resource Management (JRRM)

The primary function of the JRRM module is to optimize the overall performance of the heterogeneous radio network. This is done at a smaller time scale, and also can be addressed to the user and packet level. This includes offering service to the users based on the QoS needs of their applications and subscriptions, and distributing radio resources throughout the network to satisfy as much as mobile users ("always connected"). The module consists of a number of algorithms for dynamic spectrum allocation [8]. Ones economic-driven JRRM algorithm is based on fuzzy neural methodology and operates in a heterogeneous scenario with three available RATs, namely UMTS (Universal Mobile Telecommunications System), GERAN (GSM EDGE Radio Access Network) and WLAN (Wireless Local Area Network) and the objective is to provide, for each user, the most appropriate RAT and bit rate allocation, taking into account the following inputs: a) Technical inputs: They consist of measurements of the signal strength SSk and resource availability RAk for each RAT k. Mobile speed MS is included to take into consideration mobility constraints in the RAT allocation; b) Economic inputs: They consist of the price pj to be paid for service j and the desired total user acceptance A*.

3.10 Reconfigurable Equipment PIM

The Reconfigurable Equipment PIM (Platform Independent Model) is a formal modeling effort that aims to unify in a single technical artefact the architectural assumptions relative to the reconfigurable equipments [10]. A formal architecture methodology has been selected to structure the architecture clarification effort, based on the usage of Model Driven Architecture (MDA), defined by the Object Management Group (OMG). According to MDA, two main steps of a realisation shall be realized, namely, the Platform Independent Model (PIM), and the Platform Specific Model (PSM).

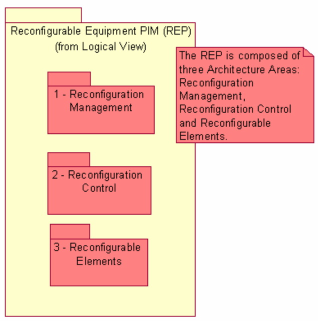

Figure 9: E²R II Reconfigurable Equipment PIM (REP)

The PIM stage focuses in capturing the implementation-independent features of the considered system. The PSM stage takes into account the implementation assumptions and models the steps towards final realization. Those two steps are conducted using a formal modeling language. In order to achieve as general recommendations as possible, the theoretical architecture work is focused on the PIM. The scope of the modeling effort being the Reconfigurable Equipment, the appropriate name is thus "Reconfigurable Equipment PIM". The PIM structure includes Reconfiguration Management, Reconfiguration Control, and Reconfigurable Elements (Figure).

3.11 Cognitive Pilot Channel (CPC)

In a composite radio environment, which also includes flexible assignments of spectrum to RATs, the cognitive capability of the terminal appears to be a crucial point to enable optimisation of radio resource usage. Assisting the elements in discovering the capabilities of the environment can boost the efficiency with which cognitive decisions are taken. Taking into account the information on the radio environment, the cognitive radio is able to switch to the most appropriate technology and frequency to deliver the required service. In order to get knowledge of its radio environment, the cognitive radio may sense some parts of the spectrum; but this may result in a very time- and power-consuming operation if the parts of the spectrum to be sensed are too large.

In this context, the "CPC" concept (Cognitive Pilot Channel) is introduced. This concept consists in conveying the necessary information to let the terminal know the status of radio channels occupancy through a kind of common pilot channel.One of the functionalities of the CPC is to broadcast data allowing a terminal to select a network in an environment where several technologies, possibly provided by several operators, are available [11].

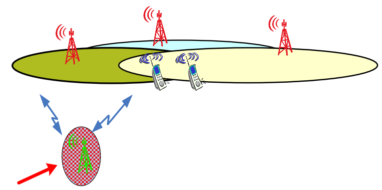

Figure 10: E²R II Cognitive Pilot Channel Concept - Related System Deployment

At switch on, the mobile terminal has no information about the surrounding technologies and the operators who deploy these technologies. In particular, in a context where the radio-mobile networks are reconfigurable, for example in case of dynamic frequency allocation, the terminal does not know, at switch on, the "current" configurations of the various networks, in particular the frequency bands associated to the Radio Access Technologies (RAT). The objective of the CPC is to broadcast information that allows the mobile to be aware of the surrounding technologies, in order to facilitate its connection to the network. When the mobile terminal is switched on, it regularly listens to this CPC and reconfigures if necessary accordingly to the information contained in the CPC.

3.12. Reconfiguration language

The Functional Description Language (FDL) has been described in [12]. As illustrated in Figure 11, it is a language based on XML and is used to describe functional configurations for reconfigurable equipment. FDL documents are interpreted by the CCM and used to determine a set of Signal Processing Modules (SPM), which are a binary configuration of the target platform that meets the requirements of the functional description.

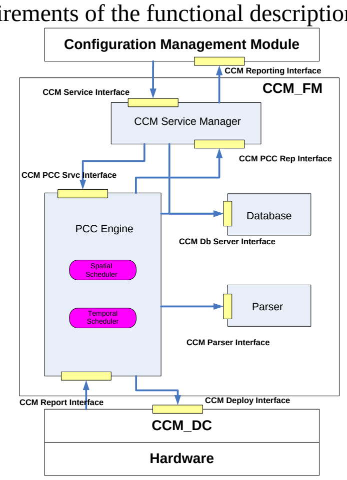

Figure 11: E²R II FDL Concept

Functional configurations are completely implementation-independent. They capture the required signal processing behavior for each RAT as a data-flow model of the constituent signal-processes, their parameters and constraints. For example the FDL for the 802.11a standard contains a hierarchical algorithm description containing processes such as FFT, Viterbi decoder, parameters such as permissible values for the Viterbi decoder polynomials and the RAT's real-time deadline constraints. The FDL presently is made up of two languages; one for describing algorithms and one for describing process parameters and arguments. Both languages are defined by an XML Schema and the data is held in conformant XML documents. The FDL languages are candidates for standardization within the SDR community and this is one of the reasons that XML was chosen; XML is a widely adopted, standard meta-language that is effectively platform independent. The CCM is required to read the function descriptions and make configuration decisions on the basis of them. The CCM must therefore use a parser that can present the XML data in a suitable manner. The parser implementation is necessarily platform dependent however the interface to the parser functionality can be constant across different platforms and technologies.

3.13. Standardization - IEEE P1900.4 WG

The IEEE 1900.4 Working Group (P1900.4 WG) [13] discusses Coexistence Support for Reconfigurable, Heterogeneous Air Interfaces in close cooperation with the E^{2}R -II project. P1900.4 system concept (figure 12) includes several Radio Access technologies (RAT) within the range of a Mobile Terminal (MT); each heterogeneous cell is assumed to be either controlled by a single operator or a meta-operator that regroups a number of individual operators. Contrary to single-link based legacy systems, the upper system concepts inherently assume the presence to several reconfigurable radio front-ends in the MTs such that the devices may choose a link to distinct RATs simultaneously. The legacy systems are not modified but three new building blocks are introduced thus keeping compatibility to them.

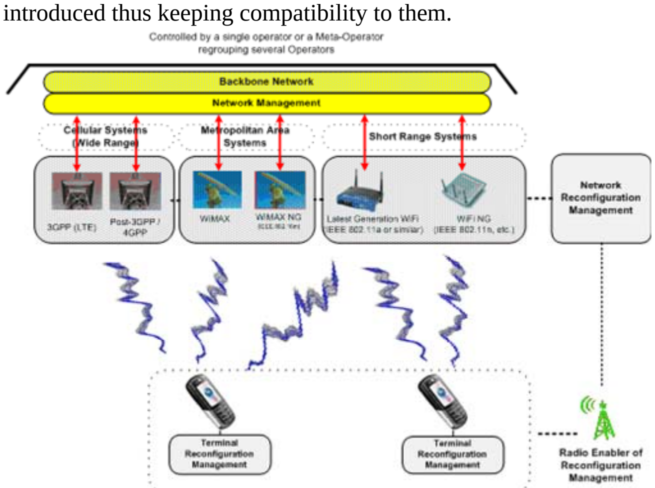

Figure 12: IEEE 1900.4 System Concept

In this sense, Network Reconfiguration Manager (NRM) provides context information and radio resource usage constraints, e.g. as illustrated in [14]. Alike, Terminal Reconfiguration Manager (TRM) takes into account context and policy information from NRM towards deciding on optimized radio usage strategies. Finally, Radio Enabler of Reconfiguration Management (RERM) is the link between the NRM and TRM and may either be a physically dedicated channel or a logical channel.

4. CONCLUSIONS

This work presented an overview of the objectives, system approach and major achievements currently investigated by E^{2}R II. Bringing full benefits of the radio eco-space diversity making heterogeneous environments transparent, flexible and intelligent is one of the main aims of the E^{2}R II project. The ultimate vision of the project is to reach a fully integrated all-IP network with reconfigurable equipment and associated discovery, control and management mechanisms.

5. ACKNOWLEDGMENTS

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