Reconfigurable Interoperability towards Seamless Communications

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***Abstract*— The need for user seamless and transparent communication across different communicating environments with consistent QoS drives the development towards future generation communications systems. In this manner, the topic of interoperability of various communicating platforms emerges as a cornerstone and crucial necessity. This paper gives an extensive overview and explains the significance of the reconfigurability and interoperability in heterogeneous networks and their role in the development towards seamless communications. In addition, the paper discusses the possibilities offered by the emerging IEEE 802.21 standard in the field of media independent handovers.**

***Keywords*— Interoperability, Reconfigurability, Vertical Handover, IEEE 802.21.**

I. Introduction

Future wireless communications systems, e.g. 3G, LTE and beyond, are envisioned to offer higher data rates, higher mobility support and seamless communication [1]. They will have to utilize a common communications platform that unifies a variety of evolving access technologies, seamless interworking and interoperability solutions and adaptive multimode user terminals [2]. In this manner, intensive research efforts are being put in several important research challenges today, i.e.:

- design of a single *wireless user terminal* able to autonomously operate in different heterogeneous access networks and exploit various surrounding information (e.g. communication with navigation/localization systems, cross-layering with different network entities) in order to provide richer user services (e.g. location/situation/context aware multimedia services);
- provisioning rich and value added *mobile services* through efficient service discovery, service management and provisioning in heterogeneous environments and increased service personalization;
- new and/or enhanced mechanisms in the *access part of the network* offering broadband mobile or semi-mobile wireless user access;
- increased *spectrum efficiency* and *channel capacity*, while at the same time provisioning ubiquitous coverage, resulting in a cost-effective solution for high data rates, increased bandwidth usability, minimized multipath effects and efficient spectrum allocation involving a cognitive approach, all leading to a boundaries movement towards broadband capabilities;
- specific technology developments such as *novel antenna technologies* (MIMO, smart units and high gain terminal antennas), sophisticated *Man-Machine-Interfaces* (MMI), solutions for increased user privacy, security and Digital Rights Management (DRM) etc.

The rapid development of various wireless communications systems worldwide and, in the same time, the rapid changes in users' profiles and market needs necessitate a common communication umbrella able to provide user transparent and seamless connections through a variety of different access network types with optimization of the user needs. Moreover, today's wireless networks, at peak hours and in the periods of emergency crisis and/or disasters, work many times at their capacity limit, very often without any redundancy and in limited spectrum availability. The key behind successful resolution of many communication challenges in heterogeneous environments is in the *interoperability*. The concept of interoperability will yield the necessity of (user transparent) *reconfigurability* and cooperativeness in various communications systems.

This paper gives an extensive overview of the rising topic of reconfigurable interoperability. Section 2 explores the pre-conditions for and the benefits of the reconfigurability in modern communications systems. Section 3 details the current status and currently proposed architectures in the field. Section 4 provides analysis of the emerging IEEE 802.21 standard. Section 5 discusses the all-IP concept and concludes the paper.

II. Peek Behind Reconfigurable Interoperability

The reconfigurable interoperability can be done at the network level, the user level or both. This brings benefits from both the network providers' perspective and the users' perspective and contributes to the robustness of the provisioning of users' requested services, while at the same time allows user seamless and transparent service management.

At the network level, the reconfigurable interoperability will offer network providers with a possibility to choose, with minimal investments, between alternative wireless access networks. The selection could be made based on several criteria such as:

- comparison between the availability of access resources and specific service requirements (e.g. channel state, outage probability, vertical handover probability, users' QoS requirements, context awareness etc.);
- load sharing and distribution between different spatially coexisting wireless networks;
- efficient spectrum sharing;
- preferred gateway selection and network discovery;
- congestion control.

Thus, any changes in the network resource availability due to network instantaneous saturation or equipment crashes can be bypassed by terminals and network components that are dynamically adapted to the new situation. In addition, the security of the delivered data can be greatly improved by means of autonomic decision making and self-healing capabilities.

Furthermore, network providers can use the reconfigurability in order to introduce value added services more easily. They can exploit the reconfigurability features at the application level introducing new services of various types without the need of provisioning at device design all the features it will need. This will lead to more vibrant market movement and increased users' choices.

At the user level, the reconfigurable interoperability will lead to more efficient end-to-end connectivity and service delivery in heterogeneous environments, easier worldwide roaming and dynamic adaptation to regional contexts, enhanced personalization and richer services. The users' devices will reconfigure based on:

- available resource usage capabilities;
- spectral agility capabilities and the level of cognitism they posses;
- minimization of the service cost when multiple underlying technologies are available;
- anticipation of user contexts and preferences.

III. Current Status in Reconfigurability

Basic reconfigurability features are already available in today's mobile communications systems, such as 3G HSDPA/UMTS, but not in commercial access systems. It is very challenging to overcome the problems related to provisioning the end-users with a variety of services (TV programs, Internet, multimedia applications, etc.) and a diversity of applications through wireless infrastructures with minimal user interventions and maximum system flexibility. Several novel architectures that exploit the reconfigurable interoperability are proposed so far. Most of them try to integrate the cellular, the IP and the broadcasting wireless technologies in an overall wireless network able to deliver broadband multimedia data to end users [3, 4].

There are two distinctive networking technologies that dominate the wireless networking today, i.e. (1) Cellular Mobile and (2) IP networks including IEEE 802.11 and IEEE 802.16 (WLANs and WWANs). Until the 4G networking paradigm becomes a reality, 3G and WLANs/WWANs will co-exist along with DVB technology (DVB-H/T/S) to offer public wireless broadband services for every user. These technologies offer characteristics that complement one-another. The last decade proposed a multitude of solutions to exploit their differences and to integrate these systems in a coherent hybrid one (an example is described in [5]) and to solve the micro and macromobility issues [6].

Several architectures that exploit the reconfigurable interoperability are proposed so far. Most of them try to integrate the cellular, the IP and the broadcasting wireless technologies in an overall wireless network able to deliver broadband multimedia data to end users. For example, the IST Ambient Networks projects [7], as one of the most comprehensive projects targeting research towards 4G, integrates the envisioned future heterogeneous environment into a single multi-radio system with powerful multi-radio resource management mechanisms and generic link layer functionality. This opens the potential to provide the "Always Best Connected" [8] approach paving the path towards the Next Generation Networking (NGN) and 4G. The IST ATHENA project [9] proposes the use of DVB-T in regenerative configurations and uses the networking capabilities of the television stream for the creation of a powerful backbone that interconnects distribution nodes within a city. As these distribution nodes make use of broadband access technologies, they enable all citizens to have broadband access. Moreover, the entire solution provides multi-service capability since the regenerative DVB-T creates a single access network physical infrastructure shared by multiple services (e.g. TV programmes, interactive multimedia services, Internet applications etc.). Architectural solutions and scenarios of interoperability between DVB-T/H and 3G HSDPA/UMTS systems are analysed in [10]. The main issues are how to interconnect these networks and how to manage the radio resources during a session. The former is targeted at how to preserve as much as possible of the individual characteristics of each system and to take benefit of the difference among them, while the latter is related to choosing the best route (through one or another wireless access system) for given link parameters and session requirements. [11] presents some preliminary ideas regarding the way to find the most appropriate traffic partitioning between different wireless access networks and their corresponding parameters, ideas grouped in the concept of reconfigurability of the hybrid wireless system. The IST ENTHRONE project [12] proposes an integrated management solution which covers an entire audio-visual service distribution chain, including content generation and protection, distribution across networks and reception at user terminals. The aim is not to unify or impose strategy on each individual entity of the chain, but to harmonize their functionality in order to support an end-to-end QoS architecture over heterogeneous networks applied to a variety of audio-visual services which are delivered at various user terminals. In order to fully achieve ENTHRONE objectives, there is currently ongoing IST ENTHRONE 2 [13] project. The IST E2R project [14] tries to reach an all-IP fully integrated network with reconfigurable equipment and associated discovery, control and management mechanisms. The IST WIDENS project [15] had an overall objective to design, prototype and validate a high data-rate, rapidly deployable and scalable wireless ad-hoc communication system for future public safety, emergency and disaster applications. The project ended with a demonstration day where a trial, consisted of five prototype nodes equipped with multi-antenna transceivers to demonstrate the benefits of MIMO signal processing in an ad-hoc networking environment, was performed. Specifically, the trial demonstrated multi-hop relaying for voice communication and access to data base replica, high bit-rates for live video surveillance, interconnection with the internet and fleet monitoring control room application, clusterhead synchronization, multi-channel operation and MIMO signal processing, four classes of QoS and conditional access control and authentication of nodes to prevent IP spoofing. The IST PACWOMAN project [16] was the first Personal Area Networking (PAN) EU project that performed the necessary research, development and optimization on all OSI layers enabling the design of a 4G terminal, i.e. low-cost, low-power, flexible PAN user terminal. This project started the user-centric paradigm that is one of the envisioned cornerstones of 4G. The IST MOBIVAS project [17] developed architectural approaches and prototypical implementations of integrated software platforms and systems which enable flexible provisioning of Value-Added Services (VAS) in mobile communication networks. The IST MAGNET project [18] and its sequel IST MAGNET Beyond project [19] completely demystifies the user centric communications paradigm and provides a solution of a number of technological issues related to networking aspects, coexistence and interworking between a multitude of different network interconnection schemes, wireless technology for Personal Networks (PNs), security and privacy. The goal is to efficiently distribute context aware services to end users.

Important research issues that facilitate the reconfigurable interoperability in heterogeneous networks and are currently under heavy investigations are the *location based services* and the *cognitive networking*. The joint analysis of these aspects [20] unleashes a novel research topic for future generation communications systems.

Location based services are provided by integration of navigation/localization systems with terrestrial/satellite communications systems. They require modern user terminals able to exploit the location/situation information and deliver context aware user services. In this manner, the Vehicle-to-Vehicle (V2V) communication paradigm is becoming increasingly popular lately. Car manufactures intensively try to integrate wireless, communication and navigation devices in their cars. The realization of the V2V communication can be achieved by the means of a *multihop* environment. There is a standardization effort in this field, the IEEE 802.11p draft amendment [21], which adds wireless access in the vehicular environment and defines enhancements to the IEEE 802.11 standard required to support Intelligent Transportation Systems (ITS) applications. This includes data exchange between high-speed vehicles and between the vehicles and the roadside infrastructure in the licensed ITS band of 5.9 GHz (5.85-5.925 GHz). Moreover, the V2V communications paradigm is increasingly intertwined with the sensor networking paradigm whereas the sensors are used inside cars, along the roads etc.

Cognitive networking [22], along with cooperative networking [23], shows potentials for highly efficient spectrum usage and spectrum sharing leading to increased channel capacity (Fig. 1). The wireless spectrum is a scarce resource that needs to be managed properly. In this manner, the cognitive networks and radios, utilizing the SDR approach, provide a prime example of efficient spectrum resource management in future wireless communications systems. Combined with location/situation information [20], the cognitive networking also provides location/situation assisted dynamic spectrum access mechanisms.

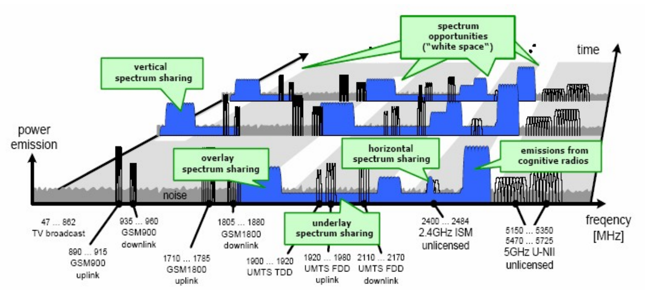

Fig. 1. Spectrum sharing of cognitive radios [2]

IV. Media Independent Handover

One of the key characteristics of new communication devices is the increased number of interfaces, e.g. Ethernet, WiFi, Bluetooth, 3GPP/3GPP2. As a result, a variety of connecting possibilities starts to emerge. In the same time, questions on the mechanisms and policies that will manage the alternatives also arise. In this manner, the emerging IEEE 802.11u [24] and IEEE 802.21 [25] standards are currently under intensive evaluation. The IEEE 802.11u is an amendment to the IEEE 802.11 standard that adds features which improve the interworking with external networks. It covers the cases where a user is not pre-authorised to use the network while allowing access based on users' relationship with an external network (e.g. hotspot roaming agreements), online enrolment or during emergency situations. The formal IEEE 802.11u standard is scheduled to be published in March 2009.

A novel solution that ensures interoperability between several types of wireless access network is given by the developing IEEE 802.21 standard. The work on the standard has begun in 2004 and it is expected to be finalized around 2010, just in time for the 4G needs. The IEEE 802.21 is focused on handover facilitation between different wireless networks in heterogeneous environments regardless of the type of medium. The standard names this type of *vertical handover* as Media Independent Handover (MIH). The vertical handover differs from the horizontal one in terms of the fact that it happens among and engages different wireless networking technologies during the handover procedure itself. The goal of the IEEE 802.21 is to better and ease the mobile nodes' usage by providing uninterrupted handover in heterogeneous networks. For this purpose, the handover procedures can use the information gathered from both the mobile terminal and the network infrastructure. At the same time, several factors may determine the handover decision: service continuity, application class, quality of service, negotiation of quality of service, security, power management, handover policy etc.

The most important tasks that arise in front of the 802.21 framework are appropriate network discovery and appropriate network selection. The network discovery and selection process is facilitated by exchanging network information that helps mobile devices determine which networks are in their current neighborhoods. As a result, the process of network discovery and selection allows the mobile terminal to connect to the most appropriate network based on certain mobile policies.

The heart of the 802.21 framework is the Media Independent Handover Function (MIHF). The MIHF will have to be implemented in every IEEE 802.21 compatible device (in either hardware or software). This function is responsible for communication with different terminals, networks and remote MIHFs and provides abstract services to the higher layers using a unified interface (L2.5 functionalities). MIHF defines three different services: Media Independent Event Service, Media Independent Command Service and Media Independent Information Service. Media Independent Event Service provides events triggered by changes in the link characteristic and status. Media Independent Command Service provides the MIH user necessary commands to manage and control the link behavior to accomplish handover functions. Media Independent Information Service provides information about the neighboring networks and their capabilities.

One of the most important aspects of MIHF is the fact that it allows for network controlled handovers (Fig. 2) and user controlled handovers (Fig. 3). The advantage of the network controlled handover lies in lower user battery consumption since the monitoring of the various networks' conditions is done by the networks themselves. The disadvantage of this handover is the need for huge signalling burden that is transferred across the heterogeneous network, as well as the need for high processing network capabilities. The user controlled handover means that the user collects necessary data and initiates the appropriate actions. The disadvantage of this approach is the high battery wastage. This interface provides to upper layers service primitives that are independent of the access technology.

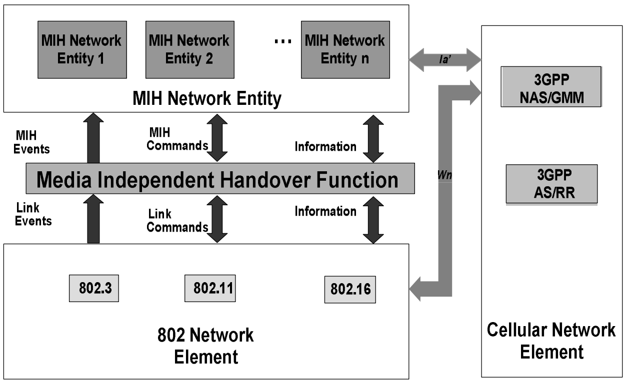

Fig. 2. Network controlled handover

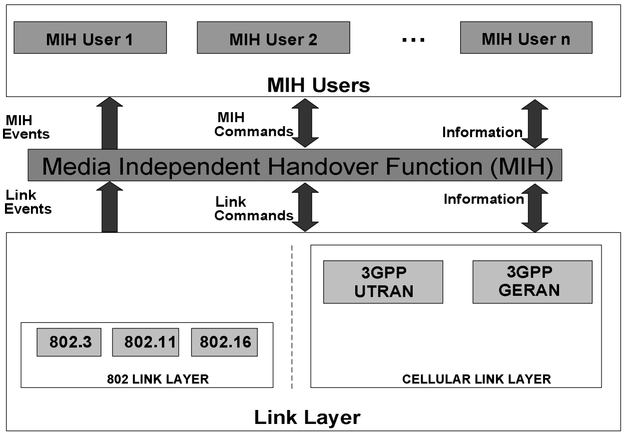

Fig. 3. User controlled handover

The IEEE 802.21 standard is still in its formative stages. However, the interest that exists both in academia and industry and the temporary works being submitted to the IEEE 802.21 comittee show that this standard may rise as a key enabler for seamless vertical handover and transparent roaming in heterogeneous networks. For example, [26] aims at providing innovative fast layer 2 handoff algorithms between WLAN and 3G cellular networks for voice services, developing wireless interworking test bed for this purpose and submitting contributions to the IEEE 802.11/IEEE 802.21 standards to alter the direction of the standards to meet the government's requirements. [27] explores how to provide mobile devices with information about current usage context in heterogeneous environments by proposing an architecture for a *Universal Information Service*. The proposed architecture is based on, reuses and extends the infrastructure components of the IEEE 802.21 standard. [28] deals with DHCP options for Media Independent Information Service (MIIS) discovery. [29] classifies multi-interface schemes for handover in heterogeneous wireless networks and proposes a multi-interface scheme for IEEE 802.21 MIH. The scheme is proposed to be able to work with standard TCP and Mobile IPv4 agent routers without particular configuration.

In a nutshell, the emerging IEEE 802.21 standard will make a major contribution towards the reconfigurable interoperability aspect of future generation wireless communications systems.

V. Conclusions (Towards All-IP)

The continuous evolution of wireless networks and the emerging variety of different heterogeneous wireless network platforms with different properties require integration into a single platform. The platform should be capable of supporting user roaming and transport of Internet traffic, while not interrupting active communications. This process is followed by the development of new mobile devices designed to deal with these various network platforms and protocols.

The end users will require a simple and efficient solution for transparent and seamless communication under these circumstances. Future systems (i.e. 4G) have recognized the Internet protocol and its extensions as a technology that allows integration of heterogeneous networks into a single, all-IP based, integrated network platform [30–32]. The advantages of this approach are:

- Availability for seamless global roaming between all technologies that support IP services,
- Integration of telecommunication services and
- Transparent selection of the underlying technology with respect to the requirements.

The idea of creation of an all-IP environment was supported by the fact that most of the wireless broadband multimedia application in the future will be IP based and that all heterogeneous networks will also use Internet protocol . IP provides independence of the underlying networks in sense of transparency. Moreover, the new mobile terminals will be capable of operating with different network platforms (e.g., UMTS and WLAN) and exploiting the information obtained from navigation/localization systems.

In order to efficiently utilize spectrum and optimize the choice of access technology, gateway and/or available networks, the user terminals and network access nodes can reconfigure appropriately, often using a cognitive approach. Cognitive radio and networking are gaining momentum and become the key enabler of reconfigurable wireless systems. The IEEE has already started a standardization effort (IEEE 802.22 standard [33]) in order to develop a cognitive radio-based PHY/MAC/air_interface for use by license-exempt devices on a non-interfering basis in spectrum that is allocated to the TV Broadcast Service.

Future heterogeneous communications systems are intended to provide high speed, high capacity, low cost per bit, IP based services for broadband multimedia. It is all about an integrated, global network based on an open system approach where the need for new technologies allowing merging, bridging and integrating separate systems into a single information delivery system is of crucial importance. The *interoperability* of various wireless platforms, their cooperativeness and adaptiveness within different network scenarios is the key towards future generation communications. The importance of this aspect is accented by forthcoming EU FP7 calls, mainly targeting cognitive radio, sensor networking, integration of localization and navigation devices, emergency communications etc.

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