Interoperability in Future Wireless Communications Systems: A Roadmap to 4G

Liljana M. Gavrilovska, Vladimir M. Atanasovski

Abstract – **Future generation communication systems will provide transparent and seamless user roaming with end-to-end QoS guarantees. As a result, the interoperability of various communicating platforms emerges as a crucial necessity. This paper gives an overview of the major 4G features and explains the significance of the network interoperability aspect and its role in the development towards the 4G paradigm.**

Keywords – **Interoperability, Reconfigurability, Wireless Systems, 4G.**

I. Introduction

Future wireless communications systems are envisioned to offer higher data rates, higher mobility support and seamless communication [1]. They will have to utilize a common platform that will unify a variety of evolving access technologies, seamless interworking and interoperability solutions and adaptive multimode user terminals (Fig. 1 [2]). The evolving 4G wireless technology is a common umbrella that covers and integrates all these requirements.

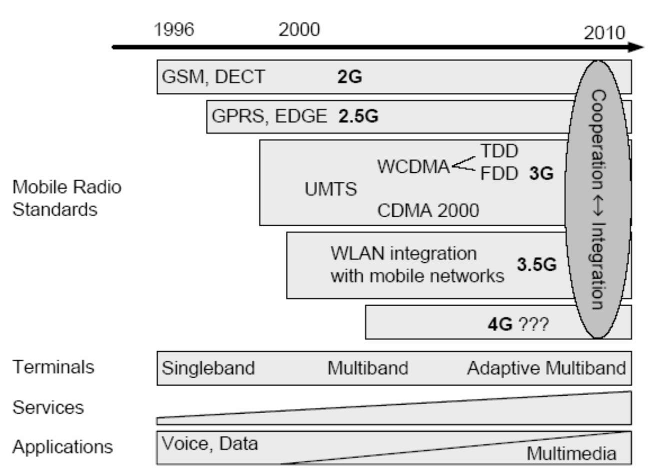

Fig. 1. Development towards 4G [2]

The latest abundance of mobile computing and communication devices generates a movement from the *Personal Computer* age (i.e. a one computing device per person) to the *Ubiquitous Computing* age (i.e. several platforms at users' request whenever and wherever needed). The huge number of personal wireless devices, which are constantly getting smaller, cheaper, more convenient and more powerful and the numerous demanding multimedia applications (context aware, reconfigurable and fully personalized) result in persistent enlargement of mobile multimedia traffic. It is expected that the number of mobile subscribers will outperform the number of fixed subscribers in the forthcoming years. The number of subscribers to wireless data services will grow rapidly from 170 million worldwide in 2000 to more than 2.3 billion in 2010 (according to "World Mobile Subscriber Markets 2005"). The same conclusions go for the number of mobile vs. number of fixed Internet subscribers (Fig. 2).

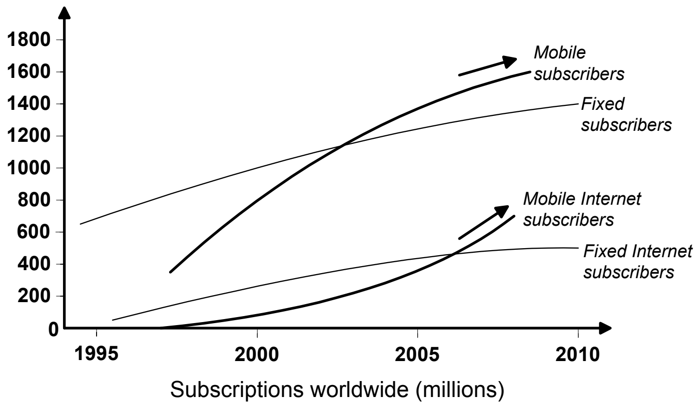

Fig. 2. The growth of the number of mobile subscribers [3]

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. 4G [4] should be exactly that seamless concept which is cost effective, simple, operable and personalized according to the users' needs. It should support the paradigm shift from technology centric to user centric concepts and should provide "anytime, anywhere, anyhow and always-on" connectivity in a seamless manner.

The key behind successful resolution of all possible communication challenges in future wireless systems is in the *interoperability*. The concept of interoperability will yield the necessity of (user transparent) reconfigurability and cooperativeness in various communications systems paving the road towards the 4G paradigm.

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This paper gives an overview on the challenging aspects in future generation wireless communications systems with a special emphasis on the interoperability issue. It explores the current status in the reconfigurable interoperability, explains the all-IP communication architecture and highlights the directions for future research. The paper is organized as follows. Section II defines the 4G concept. Section III shows an all-IP based architecture that guarantees user seamless and transparent communication with end-to-end QoS guarantees. Section IV pinpoints the most challenging research aspects towards 4G, while section V explains the need for reconfigurable interoperability. Section VI overviews the current status in the field of reconfigurable interoperability today, while Section VII elaborates the emerging IEEE 802.21 standard aimed at solving the interoperability issues in wireless systems. Finally, section VIII concludes the paper.

II. 4G: THE BIG FUSS

The latest popularity of wireless devices and applications led to the development of a huge variety of wireless devices, wireless networks and enhanced user commodity, profiles and services. The plethora of wireless computing and communications devices (e.g. laptop computers, handheld devices, PDAs, cell phones, wearable computers etc.) yields a movement towards a *ubiquitous connectivity* where a user can utilize, at the same time, several computing and communications platforms through which he can access all required information in a seamless and transparent manner whenever and wherever needed. This will yield an integration of navigation, localization and wireless communication systems leading to location/situation aware context rich user services. Moreover, the wireless technologies have to coexist with the existing and novel wired ones and be able to adapt to the user requested requirements. This is where the 4G concept finds its place.

The Fourth Generation of communications systems (or shortly 4G) is all about a global wireless communications system. It presents an open system approach and an all-IP based seamless connectivity. 4G is foreseen as an integrator that will encompass all existing, planned and future wireless and wired networks, both terrestrial and satellite. The period for 4G unleashes and step on the scene is expected to be somewhere around 2010, after the 3G and B3G solutions, Fig. 3.

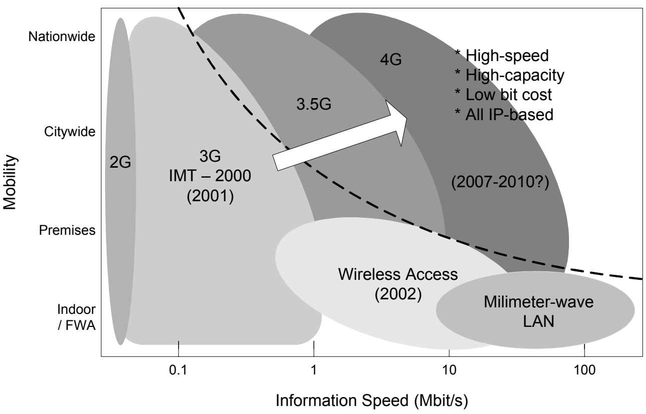

Fig. 3. Roadmap of wireless communications systems

4G is not a system designed from scratch nor it offers completely new technical solutions. 4G is more a concept whose major goals are *integration* and *convergence*. The integration should offer seamless interoperability of different types of wireless networks with the wireline backbone. The convergence relates to the convergence of different traffic types (i.e. voice, multimedia and data) over a single IP-based core network, different technologies (e.g. computers, consumer electronics and communication technology), different media (e.g. TV, cellular networks, Internet-based applications), different services (e.g. television and satellite communications) etc.

4G systems will deliver:

- All digital all-IP communication;
- Scalable composite reconfigurable environment;
- End-to-end QoS guarantees;
- Quickly deployable user services (anytime, anywhere and from any device) in a cost-effective manner, under one billing mechanisms;
- Efficient spectrum sharing and dynamic spectrum allocation;
- Advanced cross-layering techniques [5] (e.g. link layer adaptations, various protocol information piggybacking, cross-layer based MIMO etc.);
- Support for huge multimedia traffic (from several tens of megabits per second to 100 Mbps for outdoor and up to 1Gbps for indoor environments);
- Increased level of security;
- Increased personalization;
- Integration of navigation and communication systems in order to offer a variety of location/situation/context aware services;
- Diversified radio access (e.g. cellular, WLANs, ad hoc networks);
- Provisioning of advanced resource and mobility management;
- Adaptive multimode user terminals fully exploiting the cognitive networking approach [6];
- Seamless and transparent user roaming with full support for various vertical handovers.

The provisioned 4G services are expected to comprise *real-time* and *internet-like* services. The real-time services can be classified into *guaranteed* and *better-than-best effort* classes. For the guaranteed services, a pre-computed delay bound is required (e.g. voice). The better-than-best effort services can be *predictive* (need upper bound on end-to-end delay), *controlled delay* (allow dynamically variable delay) and *controlled load* (services which need significant resources for bandwidth and packet processing). Among them, the *guaranteed* and *controlled load* services are proposed to appear in 4G.

The resource management techniques in 4G systems will be fully heterogeneous. They will comprise enhanced location/situation assisted user connectivity with QoS support, enhanced spectrum efficiency and channel capacity, automatic network tracking and selection and QoS mapping and resource allocation in multi-system environments.

The mobility management includes *location registration*, *paging* and *handover*. The mobile terminal should be able to access the services at any possible place. The *global roaming* can be achieved with the help of *multi-hop* networks that can include the WLANs or the satellite coverage in remote areas in a *seamless* manner. The handover techniques should be designed to efficiently use the networks and minimize the number of handoffs. Location management techniques may be also implemented.

Congestion control in the high performance 4G networks is another important issue towards improving QoS parameters. Different approaches implement either *avoidance/prevention* or *detection/recovery* techniques. The avoidance schemes consider admission control based on measurements model or pre-computed model, while detection/recovery schemes implement flow control and feedback traffic management mechanisms.

Voice over multi-hop networks will be interesting problem, because of the strict delay requirements for voice. The network protocols should be adaptive to dynamically changing channel conditions. The digital to analog conversions at high data rates, as well as multi-user detection and estimation at base stations, smart antennas, complex error control techniques and dynamic routing will require sophisticated signal processing.

As already mentioned, the 4G network will integrate the all-IP based concept and provide an IP-based common architecture that will satisfy all necessary 4G requirements. The following section elaborates the envisioned all-IP architecture for 4G networks.

III. Integrated All-IP Architecture

The 4G systems 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 [7–9]. 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 [10]. 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.

Several features characterize the seamless all-IP architecture. The architecture should support new mobile Internet services (real-time, quality-assured conventional and streaming services) available through open interfaces to the globally roaming users. Then, the separation of the access networks from the core network (done via these open interfaces) allows evolution of wireless access networks to be independent of the core part. And finally, the all-IP architecture supports the employment of the IP technology on the transport layer (e.g., SCTP) in various parts of the network. It should provide smooth interconnection with IP-based networks of different RANs (radio access networks) and the core network. An example of an all-IP based 4G network is given in Fig. 4.

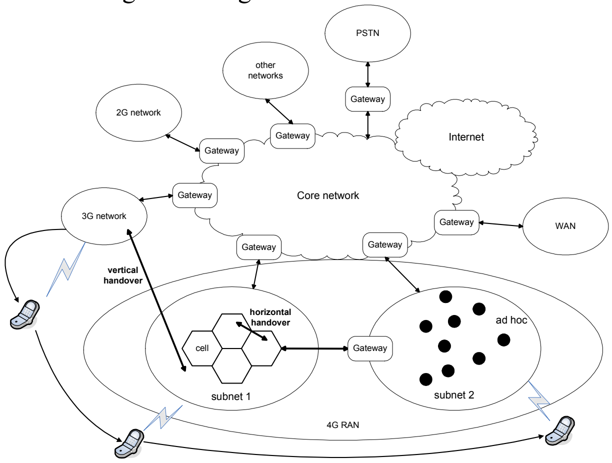

Fig. 4. All-IP based 4G network

The end-to-end IP transparency assumes that the IP packets are transmitted to the end user over the air interface with optimized spectrum efficiency (minimizing redundant and header bits). For true IP transparency, access technologies are independent. It may require introduction of IP convergence layer [7]. In that case, wireless specific signalling and resource reservation mechanisms are not necessary to achieve specific level of QoS for some applications.

The most relevant 4G IP extension is the Mobile IP protocol [11] considered as the major player in integration between all wireless as well as wirelined network platforms. Mobile IP introduces three new network entities (HA - home agent, FA - foreign agent and MN - mobile node). HA acts as a proxy to every registered node, redirecting incoming traffic from the Content Provider (CA) through encapsulation to the most recent registered location of the MN, Fig. 5. Mobile IP operates transparently from the underlying network platform. The extensions of the protocol can support regional registration management (in Gateway Foreign Agent) and fast handovers [9, 12, 13]. Mobile IP allows seamless mobility, even if it occurs between domains with previously incompatible routing models. Also, IPv6 and its mobile counterparts provide advantages regarding routing advertisements and address autoconfiguration.

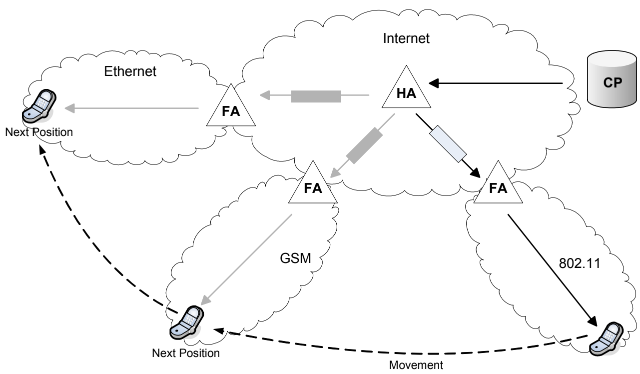

Fig. 5. Mobile IP

Realization of the all-IP concept is strongly related to achievement of end-to-end QoS and distributed resource management [14]. Mobility management (macro and micro mobility), location and context awareness and security are additional issues related to IP solutions.

RRM should fit in the overall picture of network management for next generation networks [15] that include techniques such as mobility management, security management, power management, location management etc. Different areas of management interfere with particular techniques to improve the performance. For instance, the cross-layer optimizations will be introduced as the key feature of future communication networks. They can influence the resource management and the achieved QoS performance of the overall network. Other examples can be found in service discovery techniques, security mechanisms, mobility modelling, location and context awareness

Providing end-to-end QoS requires close cooperation with the network management (i.e. resource and mobility management). This is a demanding task due to the dynamic nature of the 4G network and the possible nonnegotiable QoS between users and networks, such as in the case when ad hoc networks are used as an access domain. QoS provisioning under these circumstances may combine pure IP solutions with underlying radio technologies [16]. The IP QoS consists of service quality management and QoS enforcement techniques (adopted and balanced through RRM control). Quality enforcement mechanisms, such as IntServ and DiffServ techniques can be used to control the IP flows through queuing, marking and dropping the packets [17]. Adopted enforcement techniques should conform to customer expectations, network type and traffic characteristics. QoS management interacts with users, in the form of Service Level Agreements (SLAs) [18] and concerns with the propagation of those expectations through the network in the form of network-level and element-level policies. Different QoS metrics are defined as appropriate for the ingredient 4G network components. They may take the form of metapolicies which combine different metrics such as mobility, characteristics of radio channel, cell size and orientation, and handover acceptance metrics.

The integrated all-IP environment is an environment of ambient intelligence [19, 20]. Ambient intelligence places the user at the center of the information society and supports the shift towards the user-centric paradigm. This integrated all-IP network is lately referred as Next Generation Wireless Network (NGWN) [21, 22].

Following section highlights the most intriguing and challenging research aspects in future wireless communications systems.

IV. Research Challenges in Future Wireless Communications Systems

The 4G paradigm is under intensive research efforts. There are numerous research groups and research projects worldwide targeting their work at making the 4G environment operable. However, there are several crucial issues that need to be investigated until the 4G becomes our reality. This section will pinpoint the most important research challenges that face the wireless communications systems research world today.

A. User Terminals

The 4G potential will require the design of a single wireless user terminal able to autonomously operate in different heterogeneous access networks. Moreover, this terminal will have to 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). The richness of the services will necessitate higher bit rates, which will be the main driving factor towards broadband multimedia development. Also, the terminal awareness will put strong emphasis on the concept of cognitive radio and cognitive algorithms for stand-alone terminal reconfigurability and interoperability.

The design of this multistandard/multimode cognitive user terminal faces several problems. There must be reductions in cost, size, power consumption and circuit complexity that will lead to a reconfigurable user terminal which is cheap, wearable and conformant. At the same time, in order to satisfy user commodity, the multimode user terminal will be equipped with advanced features (such as a megapixel camera and/or high-resolution video camera) resulting in higher bandwidth need both in uplinks (for sending) and downlinks (for receiving high amounts of multimedia content). In addition, sophisticated autonomous network tracking and dynamic network selection algorithms must be developed. The 4G scenario will require that every communication session for a particular service utilizes the most appropriate underlying network technology. For this purpose, advanced spectrum access and spectrum sharing mechanisms exploiting cognitive (SDR-based) radios are currently hot research topics.

B. Mobile Services

The 4G paradigm imposes serious challenges to the various services that are to be offered in future wireless communications systems. Issues such as efficient service discovery [23], service management and provisioning in heterogeneous environments and increased service personalization will increasingly emerge.

Sophisticated 4G service discovery mechanisms will combine the location/situation information and context awareness in order to deliver users' services in a best possible manner. Additionally, future mobile services will require more complex personal and session mobility management able to provision personalized services through different personalized operating environments to one address (the user terminal address). Therefore, unique address assignment and management techniques in heterogeneous environments will be a must. Today, the Mobile IP Protocol [24] is considered a major player in this field as it provides seamless mobility and unique address opportunity. However, there are still certain doubts on whether Mobile IP or Session Initiation Protocol

(SIP) [25] should be the core 4G protocol and also whether the service delivering framework should be network layer based or application layer based. In addition, the users of a 4G network will require high speed streaming real-time applications with high QoS and bandwidth usability. Hot research topic that attracts significant attention is the opportunistic scheduling based video streaming. In this manner, UDP is slowly, but surely, losing the battle against TCP as a transport protocol for video streaming. Also, the SCTP [26], with its multihoming characteristics, can provide extremely reliable streaming services in a vibrant heterogeneous environment where a user can switch from one network to another. This makes SCTP a potential candidate for transport layer technology in the 4G scenario.

Finally, there will be a need for more intelligent billing systems (multi-operator oriented) able to manage a single user bill in a situation where the user may subscribe to multiple service operators for multiple different services. This will yield a design of new, packet switched oriented, billing and accounting policies for 4G users that will handle QoS dependent charging, real-time billing information support, interworking prepaid systems support, IP traffic billing support etc.

C. Access Network Issues

The development towards 4G will embed new and/or enhanced mechanisms in the access part of the 4G network. New, low cost access infrastructures (fixed, nomadic and hotspots) offering broadband mobile or semi-mobile wireless user access will emerge and co-exist. In addition, the access part will comprise a variety of connections, i.e. point-to-point, point-to-multipoint and multi-hop relaying based mesh concepts [27]. Mesh connectivity can provide increased system coverage and higher reliability. Also, digital radio and TV broadcasting systems will gain more attention and will be integrated in the overall heterogeneous scenario.

The development of new and/or enhanced access part of the 4G network is mainly related to the increased complexity of the resource allocation and management techniques in heterogeneous scenarios. The sophisticated resource management algorithms will need to cope with issues such as seamless terminal mobility management (vertical handovers), integration and interoperability of diverse networks, end-to-end QoS provisioning and maintenance, increased fault-tolerance and survavibility of the whole 4G network, high level of security, intelligent packet and call routing, intelligent gateway discovery and selection procedures and design of an unified protocol stack and vertical protocol integration mechanisms.

D. Communication Issues

The main communication challenges in the 4G picture lie in the need for increased spectrum efficiency and channel capacity, while at the same time provisioning ubiquitous coverage. It will result in a cost-effective solution for high data rates, increased bandwidth usability, minimized multipath effects and efficient spectrum allocation involving a cognitive approach. Potential 4G technology enablers are OFDM based air interfaces, UWB radio transmission and smart antennas. Handling their drawbacks in an intelligent manner will ease the development towards 4G.

One of the cornerstones of the 4G picture will be put on the Radio Resource Management (RRM) and the corresponding (preferably dynamic) signalling of resource requirements. The RRM has a significant impact on the fulfilment of QoS requirements and on obtaining higher spectral efficiency. It encompasses several functions such as handover, power control, admission control, congestion control and packet scheduling [28]. However, there are numerous challenges yet to be addressed. Novel schemes for distributed dynamic channel allocation and call/connection admission control are searching for near-optimal computationally inexpensive distributed solutions [29]. New, adaptive and hybrid schemes should optimize the control of the radio access bearers for real time and non-real time traffic. Sophisticated traffic engineering should offer new approaches to handle bursty multimedia traffic, random arrival and reading times and random number of packets per session, without jeopardizing network coverage and capacity [28, 30].

E. Specific Technology Developments

The development towards 4G will require additional specific technological achievements. For example, the antenna technologies will evolve in order to significantly contribute to the spectral efficiency and higher bandwidth issues. In this manner, improvements regarding the Multiple-Input-Multiple-Output (MIMO) technology, smart units and high gain terminal antennas are to be realized. Furthermore, sophisticated Man-Machine-Interfaces (MMI) that provide advanced speech recognition and analysis will be developed. Finally, solutions for increased user privacy, security and Digital Rights Management (DRM) must be derived.

This section explored some of the most important research issues for future generation wireless communications systems. It is obvious that the interoperability of different technologies and the terminals' reconfigurability and cooperation will be crucial challenges. The following section will justify this statement.

V. Why Reconfigurable Interoperability?

Previous sections highlighted the reconfigurable interoperability as one of the cornerstones of 4G systems. A natural question that arises is why the concept of reconfigurable interoperability is of upmost importance for the road pavement towards 4G. The answer lies in the rapid development of various wireless communications systems worldwide and, in the same time, the rapid changes in users' profiles and market needs. As a consequence, it is common that the corresponding wireless networks work many times at their capacity limit and, very often, without any redundancy. These are factors of risk, especially at peak hours and in the periods of emergency crisis and/or disasters, which must be dealt with while the development of the 4G concept undergoes.

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, since they have the possibility to introduce new services of various types without the need to provision 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 of the heterogeneous 4G system 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 (the information will be provided by navigation and/or localization systems);
- 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.

This section clarified the crucial role of the concept of reconfigurable interoperability in the development towards 4G. It is easily seen that the mechanisms of reconfigurability refer not only to the physical layer, but span across the entire protocol stack (including cross-layering optimizations). The following section will give an overview of the current status in this field.

VI. Current Status in Reconfigurable Interoperability

Today's evolution of communications systems towards 4G follows a convergence and integration market trend. Namely, various networking solutions (fixed, mobile and broadcasting) are being merged and integrated creating a new environment that will enable potential users to access different types of communication services (possibly multiple services) anytime, anywhere. Basic reconfigurability features are 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.

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 [31]) and to solve the micro and macromobility issues [32].

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 [33], 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" [34] approach paving the path towards the Next Generation Networking (NGN) and 4G. The IST ATHENA project [35] 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 [36]. The main issues are how to interconnect these networks in order to preserve as much as possible of the individual characteristics of each system and to take benefit of the difference among them and how to manage the radio resources during a session choosing the best route (through one or another wireless access system) for given link parameters and session requirements. [37] 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 [38] 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 [39] project. The IST E2R project [40] tries to reach an all-IP fully integrated network with reconfigurable equipment and associated discovery, control and management mechanisms. The IST PACWOMAN project [41] 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 user terminal. This project started the user-centric paradigm that is one of the envisioned cornerstones of 4G. The IST MOBIVAS project [42] 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 [43] and its sequel IST MAGNET Beyond project [44] 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. 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. Cognitive networking, along with cooperative networking, shows potentials for highly efficient spectrum usage and spectrum sharing leading to increased channel capacity (Fig. 6). Combined with location/situation information, the cognitive networking provides location/situation assisted dynamic spectrum access mechanisms.

Another important trend today is the decrease of user terminal costs based on miniaturization and integration, with additional benefits in decreasing the terminal power consumption and increasing the autonomy. This trend is manifested also to other equipments from the radio access networks, like the base station transceivers. The result is a cheap, but rigid structure of wireless access network. As a consequence, many architectural solutions aimed at building a hybrid wireless communications system consider the use of interoperability modules located in the terminal equipment or in a distribution equipment and at the base station or radio access network level as best choice [45].

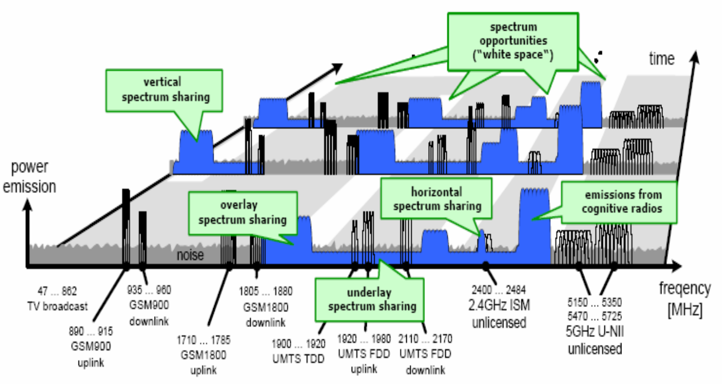

Fig. 6. Spectrum sharing of cognitive radios [2]

VII. Media Independent Handover

The latest telecommunications blossom and release of new wireless standards such as the new versions of WLAN and WMAN standards (e.g. IEEE 802.16e), represent new challenges in the development of interoperability solutions in the heterogeneous 4G environment. Various wireless systems differ according to their physical characteristics, access mechanisms and even service distribution. The focal point in this scenario is His Majesty, *the user*. Therefore, the 4G paradigm necessitates an umbrella that will seamlessly and transparently allow the user to roam across regions covered with different wireless technologies and still obtain the preferred service. In this manner, the emerging IEEE 802.11u [46] and IEEE 802.21 [47] 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 goal of 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. 7) and user controlled handovers (Fig. 8). 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.

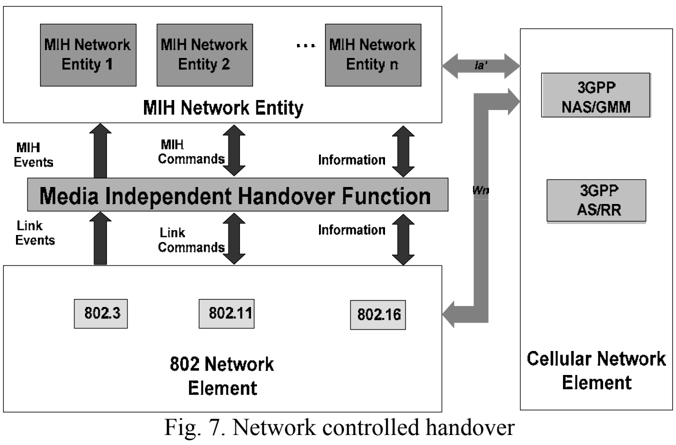

Fig. 7. Network controlled handover

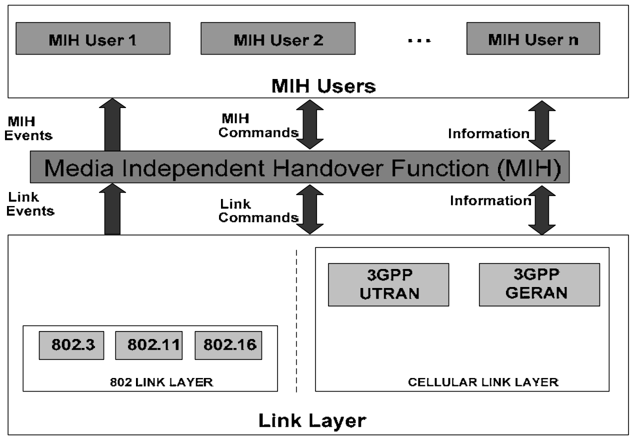

Fig. 8. User controlled handover

The IEEE 802.21 standard is still in its formative stages. However, the interest that exist both in academia and industry shows that IEEE 802.21 may be the key enabler for seamless vertical handover and transparent roaming in heterogeneous networks. As a result, this standard will make a major contribution towards the reconfigurable interoperability aspect of future generation wireless communications systems.

VIII. CONCLUSIONS

The 4G paradigm is already on the road. It is expected to become a reality and the major players are taking their roles. Developed countries (such as USA, Japan, Korea, Germany, etc.) and major wireless industries are already implementing 4G functionalities in a limited range of devices and applications.

4G is 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. At the current level of development, there are several technologies each capable of performing some of the functions like broadband data access in mobile or nomadic environments, supporting voice traffic using voice over IP (VoIP) etc. However, what is of crucial importance is the need for new technologies allowing merging, bridging and integrating all the separate systems into an information delivery system of the twenty first century. Among the most important features that trace the roadmap towards the 4G arises the *interoperability* of various wireless platforms, their cooperativeness and adaptiveness within different network scenarios [48].

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 [49]) 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. An example of the emerging paradigm of cognitive network is given in Fig. 9 [2].

4G allows heterogeneous platform with variety of advanced multimode user terminals, different users' profiles, broadband multimedia capabilities and middleware structures, paving the way to new R&D directions and emerging standards. This paper gave an overview of the 4G platform, demystified the most important research challenges that are to be overcome, described the user-centricity shift and highlighted the reconfigurable interoperability and corresponding cognitism as key research areas towards 4G.

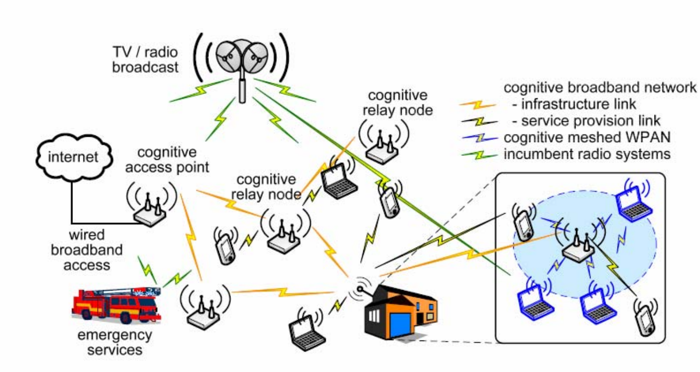

Fig. 9. Reconfigurable wireless networks

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