Strategic and Technological Challenges for Wireless Communications beyond 3G

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Abstract: **In order to facilitate and to meet the ever increasing demands for the wireless communication in the next decade and also to satisfy the high data rates for the new services, the future development of 3G (IMT2000) and systems beyond 3G (B3G) are foreseen. This article presents the need for these developments and motivations for systems beyond 3G taking into account both strategic and technological challenges to be faced. Moreover, the concepts and potential technologies involved including multiple air-interfaces, efficient spectrum allocation and utilisation for the success of systems B3G are briefly reviewed.**

Index Terms: **3G, IMT2000, systems beyond 3G, frequency spectrum, heterogeneous wireless access, mobile architectures.**

I. INTRODUCTION

Wireless communication industry is growing drastically and nowadays more than half a billion mobile users having an access to cellular systems can take the advantage of "*network connection while being mobile*." Several countries of northern Europe already experience penetration ratios over 70% while less developed countries take this opportunity to develop their lagging telecommunication networks. Many analysts forecast that there will be over one billion mobile subscribers within the next decade.

The recent convergence of the Internet and mobile radio has also accelerated the demand for different users and its merge with mobile access having personal light and low-cost radio terminals is the key objective of the industry professionals. Consequently, a new wave of mobile phones is expected offering full "*internet in the pocket*" as a result of the introduction of 3G systems of the ITU IMT2000 (International Mobile Telecommunication 2000) family [1]–[3].

Moreover, radio local loop systems are going to complement the wired networks thanks to their mobility, high data rates and low cost. Satellite systems are planned using both geo-stationary and non-geo-stationary (low earth orbit) systems. The regional and global coverage of these systems will make new data services available to people literally worldwide. Moreover, short-range systems are also expected to grow exponentially, replacing the need for connection cables but again increasing the need for frequencies.

Today's 2G mobiles - based on the Global System for Mobile Communication (GSM), Code Division Multiple Access (CDMA) or Time Division Multiple Access (TDMA), that is, IS-136 - are being evolved towards the General Packet Radio Service (GPRS), then Enhanced Data rates for GSM Evolution (EDGE) and finally to the 3G /IMT2000-Universal Mobile Telecommunications System (UMTS) that is European implementation of IMT2000 that exploits WCDMA (Wideband CDMA) technologies. 3G/UMTS is being introduced simultaneously as GSM/EDGE continues to progress. It is evident that each 3G mode follows from a specific 2G predecessor and uses that legacy protocol as one of its 3G operating modes. These systems provide wide area outdoor and indoor coverage with 3G rates projected to 2Mbit/s.

In addition to these wide area cellular networks, there are also wireless transmission technologies including DAB (Digital Audio Broadcasting) and DVB (Digital Video Broadcasting) for wide area broadcast, LMDS and MMDS (Local and Multi-channel Multipoint Distribution Systems) for fixed wireless access, IEEE 802.11b, 11a, 11g, 11h, and HIPERLAN2 for WLAN (Wireless Local Area Networking) based on cellular mode of operation. If, as expected, the cost of the required technology follows a steep declining curve, WLAN may become ubiquitous in all environments. Future wireless broadband local area networks are expected to provide up to 1 Gb/s capacities in the longer term. These technologies and their derivatives, under the general heading of wireless local area networks, may well prove to be the infrastructure components of future cellular networks [4] and [5].

All these technologies have been optimised for operation in a particular range of service bit-rate associated with certain speed of user mobility. In this complex environment, the "*systems beyond 3G*," e.g., "**B3G**" are required to provide universal connectivity of both fast and slow moving subscribers. Fig. 1 depicts both historical evolution of cellular systems from 1G to 3G and also predicted evolution of 3G towards the systems B3G in terms of both services and technological aspects.

B3G systems are being treated by many international Forums such as European Commission initiated Wireless World Research Forum (WWRF), ITU-R WP8F Vision Group, as well as recent activities in enhancing WLAN and WMAN (Wireless Metropolitan Area Network).

In this contribution, we aim to familiarise our readers to the evolution of 3G and systems B3G. Therefore, we stress the reason "***why***" we need more proactive approaches linking both strategic and technological challenges for evolution of 3G and even B3G systems and in "***which***" time period it may be deployed and finally "***what***" the new system after 3G is. First, we start with the motivations of such systems for different players in the wireless domain (end users, content providers, ser-

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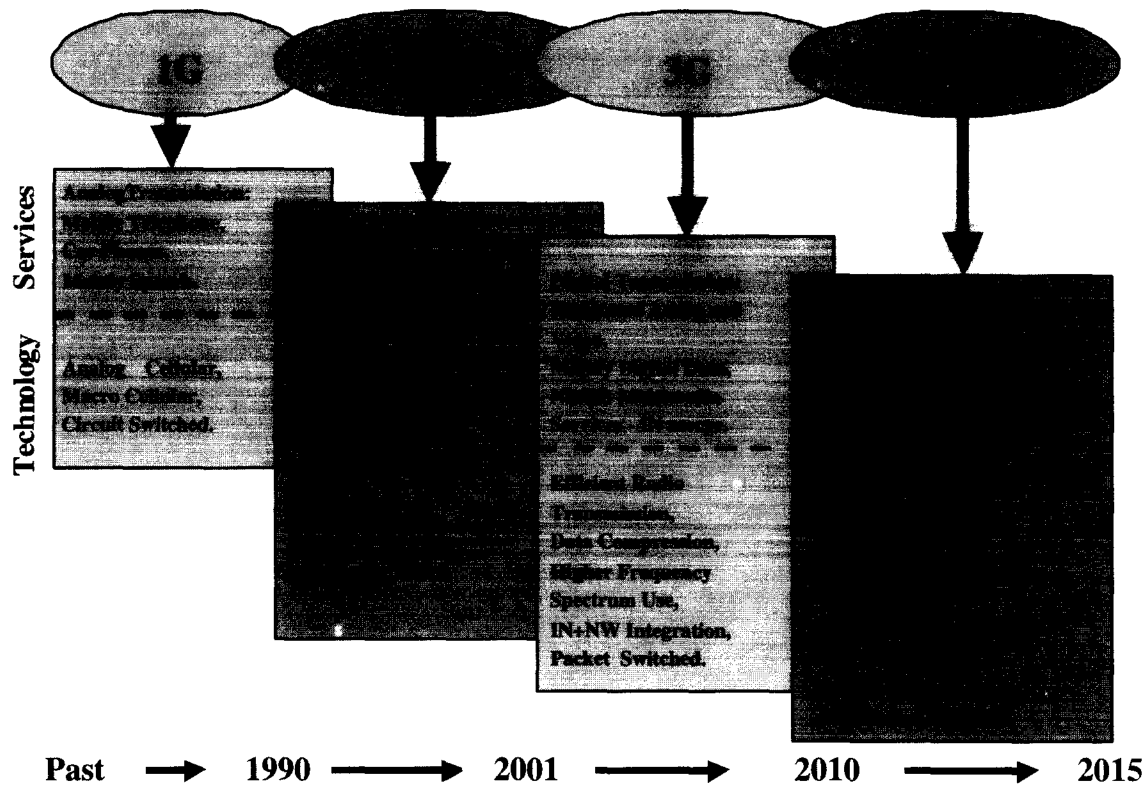

Fig. 1. Evolution of cellular networks from 1G to beyond 3G (NB/BB=Narrowband/Broadband).

vice providers, operators, and manufacturers). Then, we highlight the marketing aspects and new potential services. From the previous experiences gained in 2G and 3G for wireless communications, it is obvious that both strategic and technological challenges play significant role for the success of systems. Both aspects are discussed here, considering connected politics, time line, marketing potential, frequency spectrum availability and also novel technologies. Technological trends include Software Defined or reconfigurable radio (SDR), Ultra Wideband (UWB) concept and heterogeneous wireless access technologies like Multi-Standard Radio Access Network Architecture (MxRAN) and Multi-Standard Radio Resource Management (MxRRM). We believe this Unified Radio access approach will provide the platform for integration of current 3G and future air-interfaces to build the public mobile radio network for B3G [6].

II. CONCEPT OF B3G SYSTEMS AND MOTIVATIONS

In order to maintain and better develop the competitiveness of the telecommunication industry, it is essential to introduce evolutions in 3G/IMT2000. This expansion is also organised in order to improve the offered services and the spectral efficiency to satisfy the needs of mobile communications for the near future. The perspectives for B3G systems are to be seen in the overall context of converged interoperability of core network with a full range of wide-area mobile and local-area mobile/access systems. Derivatives of HiperLAN2 with very high bit-rates will be an essential component of these future architectures.

Therefore, in order to meet the rising expectations of mobile subscribers, the work on B3G systems has already started within ITU-R. The main idea is to evolve and enhance 3G/IMT2000 continuously by deploying and upgrading current 3G technologies over at least 10 years or more. Eventually, this approach will also promote the development of new services and applications. However, both strategic and technological challenges to be faced are enormous. From radio access perspectives, it is foreseen that 3G will further develop the existing technology in order to enhance market stability and will promote the development of an expanding number of services and applications. Fig. 2 summarises the potential capabilities of new systems under study [7].

As depicted in Fig. 2, future development and a new capabilities of 3G/IMT2000 are the path to B3G systems. The first one will support new applications and services. With the capacity of extended bit-rates from 2 Mb/s up to possibly 20 Mb/s in around year 2006, new services will be feasible. At this stage, an additional spectrum may be required by some operators for the deployment of new services.

For new systems, there may be demand for a new wireless access technology for the terrestrial component in around year 2010. It is foreseen that this novel radio interfaces will be able to support up to 100 Mb/s for high mobility and up to 1 Gb/s for low mobility like nomadic/local area wireless access within the same time frame. It should be clearly stated that all these numbers (100 Mb/s and 1Gb/s) are indicative and they provide a guidance for a research community for the new systems, therefore they are not to be considered as definitive requirements for B3G systems.

Moreover, expected uses of radio for billions of subscriber will eventually increase the need for radio spectrum drastically

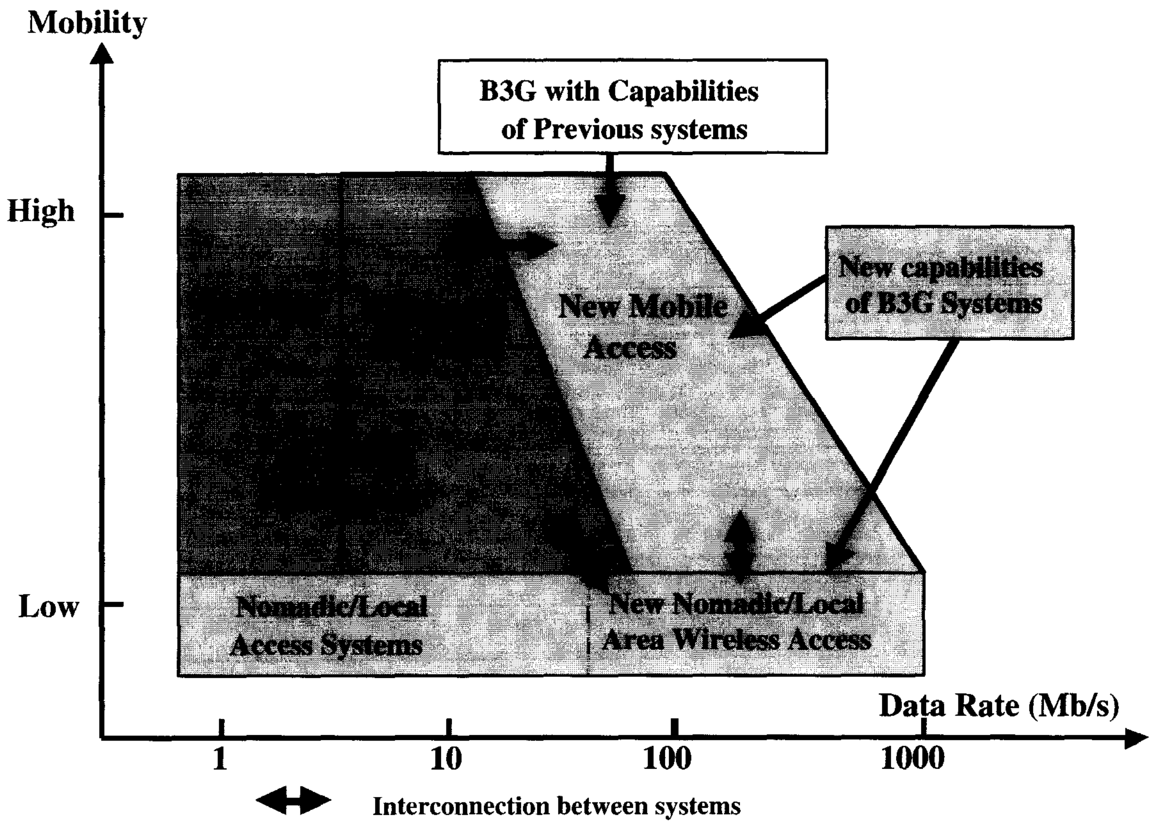

Fig. 2. Potential capabilities of 3G/IMT2000 and B3G.

and so many simultaneous remedies will have to be found. The easiest is apparently to transfer frequencies from some domains to others. Of course, technical advances will also contribute. From bandwidth and spectrum point of view, there should be enough spectrum to launch the new services taking into account many factors such as re-use factor, duplex techniques, guard bands, number of operators and RF bandwidth of a single carrier.

Table 1 summarises the motivations for B3G systems from different players point of view [7].

III. STRATEGIC CHALLENGES FOR B3G SYSTEM

Considering the timing, costs, huge investment by operators and lack of integration in the planned 3G systems have gave opportunity to present mobile subscribers to ask for future directions. The main players in the wireless communications such as manufacturers and operators are to be ready for such scene. The challenges for the future systems via the enhancement process of 3G are economic, political and technical. In the following sections, we present major trends that will both play a crucial role in forming B3G system cluster by making it possible for new businesses, alliances and value chain to emerge and determine how quickly we can deploy and implement the dream of full data access, anywhere, anytime, at low cost. Furthermore, availability of the frequency spectrum is considered as one of the key strategic challenges since it is related to international decision making bodies, politics of each country's defense, public service requirements and regulatory agencies.

A. Connected Politics and Time Lines

It is well known that GSM has stemmed from the political drive to build the European Union and has been presented as a showcase project. Similarly, the achievement of a global, 3G generation mobile system become a symbol of successful worldwide political co-operation. As a result, international political willingness played a major role for defining ITU-R IMT2000 family of standards. World politics can either remain unchanged during long periods (that is unlikely!) or can vary so quickly that the advent of new systems becomes possible or even necessary. Recent approaches within the international bodies such as WWRF Forum and ITU-R seem to be in line with the latter case. These groups are working extensively on the enhancement of 3G/IMT2000 and moreover, on B3G systems. Presently, Regional views are almost in line, although ITU defined Region 3 (Asia and Far East) countries are well in front for pushing the B3G systems due to their capacity limitations.

Time line in realising both development of 3G/IMT2000 and the B3G systems are the major issue. From the previous experiences in 2G and 3G, it is foreseen that standards development for each new generation system technology needs about a decade and it also requires another decade for commercial maturity. In case of 3G, the research activities and standardisation work had started in the late 80s (European Commission funded RACE Mobile Project for UMTS) and early 90s (when the GSM was commercially deployed in Europe). In the same way, considering that 3G systems are being deployed nowadays in many parts of the globe, time has come to start the preparation of the

Table 1. Motivations for B3G Systems from various players point of view.

Players for beyond 3G Systems	Motivations
END USERS	• Universal Mobile Access • Quality at reasonable cost • Long equipment and battery life • Improved Service capabilities • Extensive range of terminals • User Friendly billing capabilities
CONTENTPROVIDERS	• Flexible billing capabilities • Ability to match content to user demands in terms of terminals, location,
SERVICEPROVIDERS	• Fast, open service creation • QoS and security assurance • Automatic service adaptation as a function of the bit rate
OPERATORS	• Optimisation of the spectrum • QoS and security assurance • Capability to provide universal services • Reconfigurable network configuration • Cost effective terminals • Smooth transition from 2G to 3G and beyond 3G • Efficient Sharing capabilities between 3G and new ones • Flexible billing capabilities
MANUFACTURERS	• Capacity to realise economics of scale • Ability to access to a worldwide market • Open physical and logical interfaces between modular and integrated subsystems • Reconfigurable platforms for fast and low cost developments • International agreements for innovative technology patents

future of 3G/IMT2000 and B3G systems. Technology and services to be offered should be identified. It is also possible that drastic technology development may help to introduce these new systems before the usual time frame of a decade. Moreover, it is most probable that in the short-term, B3G systems will co-exist along with the enhanced 3G solutions.

Furthermore, time line does not only depend on the standardisation process and the technology achievement but, also depends on the market trends, user demands, spectrum availability (allocation of the new bands and assignment of these bands that is a long process as in many countries the bands are already being used by other services - therefore re-farming process can take a considerable amount of time) and finally regulatory considerations. ITU-R studies so far show that in the short-term (up to about year 2010), future development of 3G/IMT2000 will be envisaged with the enhancement of capabilities of the initial deployment within the frequency bands identified by World Radio Conference 2000 (WRC2000)- using the IMT2000 extension bands after re-farming process in many countries. In the longer-term (from 2010 onwards), introduction of new air-interfaces can be a part of evolved 3G systems. These interfaces are expected to add significant new capabilities along with the additional frequency bands. It is also believed that the interfaces for B3G systems will exploit the new frequency spectrum that is to be identified by WRC2007. Hence, a speculative time scale of matured B3G system is foreseen in the horizon of 2015 as depicted in Fig. 1.

B. Marketing Aspects: Creation of New Services

The number of world-wide terrestrial mobile subscribers has increased from 300 million in 1997 to 800 million in 2001 and moreover, the report on "*The world-wide Mobility - 2001*" from Telecompetition predicts that it will reach 2200 million by 2010 [8]. User demands increase continuously with the introduction of new services and applications - more the services, more the users. In early days of 3G, services and traffic will remain restricted by existing technologies and low interworking capabilities between the different access networks. Both enhancement processes of 3G and B3G systems, will remove these constraints and eventually will bring enhanced possibilities of usage in certain wireless environments.

B3G systems are expected to improve the coverage in dense areas to absorb more traffic by creating a new air-interface or authorise the roaming between deployed hot spots. New technological solutions would dramatically increase the service capabilities delivered over radio network. B3G systems will also align diverse access technologies to deliver best services to the subscribers considering both cost and bandwidth efficiency. Although it is a difficult task to predict the future services that are basically broadband nature, we can envisage that during a decade, every person will have a dozen processors/sensors around his body, providing means for environment interactions such as universal computing and Personal Area Networks (PAN) of intelligent applications (see Fig. 1). Most of the people will have huge databases in servers, for home and office (music, film and entertainment). Tele-shopping, tele-learning and tele-working will be more dominant. Moreover, computer screens will replace the books and interactive teaching and distance learning will be more dominant. In addition, B3G systems are expected to enhance performance in transferring real-time high-speed data. For example in tele-medicine field, paramedical emergency units in remote location can be provided with access to medical records and assistance from medical specialists through high quality videoconference and virtual guidance.

C. Frequency Spectrum Availability

Radio spectrum is a unique, ubiquitous natural resource shared by various types of services. Unlike many other natural resources, it can be repeatedly reused. In practice, though, it remains a finite resource and it can only accommodate a limited number of simultaneous users. The use of the radio spectrum is regulated and the assignment procedures are changing. Previously, the spectrum allocation was done within a framework of well-established stable and closed international, regional and national bodies and the management was purely pursued on the basis of technical considerations. However, in the changing environment, the spectrum allocation is being influenced by both business driven forces and international trade considerations [9]. In this context, the spectrum activity for 3G/IMT2000 has been going on since 1992. The World Administrative Radio Conference in 1992 (WARC92) and WRC95 defined the radio spectrum to be used by 3G systems (both terrestrial and satellite systems for UMTS in Europe and for IMT2000). A total of 230 MHz was identified for use by countries wishing to implement IMT2000 (known as core bands). Some parts of this band (1980-2010 MHz and 2170-2200 MHz) are reserved for satellite component of IMT2000.

As a consequence, many countries have chosen licensing processes based on auctions or beauty contests. The relative merits and demerits of the licensing processes are an open issue. Although auctions offer important advantages of economic efficiency (fairness, greater transparency and less favourable to new market entrants), they may not be suitable in all circumstances. For example, they are impractical for high volume, low value licenses, such as private business radio.

It is well know fact that due the enormous volume of traffic forecast, the above-allocated band would not be sufficient. Based on the extension band of 160 MHz agreed by 3 Regions, WRC2000 in Istanbul identified additional spectrum requirement of 160 MHz in all Regions 1, 2, and 3. To complement the core spectrum, the conference reached a global consensus to identify additional bands for the terrestrial components of 3G/IMT2000, namely:

- *806 to 960 MHz,*
- *1710 to 1885 MHz,*
- *2500 to 2690 MHz, form which 2500-2520 MHz, and 2670-2690 MHz are identified for satellite component of 3G terrestrial system.*

These bands will provide extra capacity to support the future mass market for mobile multimedia services (two billion users estimated by the end of the decade). This allocation also paves the way for the introduction of 3G services, even in regions where the core spectrum has not previously been available for IMT2000/UMTS. Furthermore, mobile users with these spectrum extensions will be able to access their information services using a cheap handset wherever they travel. All these bands provide the additional 160 MHz required to support the anticipated future traffic. The decision regarding the extension bands will have a major impact on the 3G licensing process. More than a hundred licenses are to be awarded to operators of high capacity 3G systems within 12 to 18 months.

Additional extension bands to meet the enormous volume of traffic forecated were allocated for use by administrations wishing to implement IMT2000 services in addition to those adopted at WARC92. WRC2000 adopted two key resolutions concerning the terrestrial components of IMT2000/UMTS: Resolution 223 (additional frequency bands above 1 GHz) and Resolution 224 (additional frequency bands below 1 GHz). The decisions made at WRC2000 allow countries flexibility when deciding how to implement IMT2000 services.

It is clear that in many countries the bands identified for 3G systems are already heavily used for other vital services which, for economic and strategic reasons, cannot be readily relocated. For example, in the USA, the 2500 to 2690 MHz band is used by the Instructional TV Fixed Service (ITFS), Multipoint Distribution Service (MDS) and Multichannel Multipoint Distribution Service (MMDS). The only solution is to share the allocated 3G bands with existing services. Similarly, the 1755 to 1850 MHz band is used for fixed microwave communication systems, military tactical radio relay radios, air combat training systems, high resolution airborne video data links and so on.

ITU Working Party WP8F has been given the responsibility for the specific studies in preparation for WRC2003 (sharing implications, harmonised frequency arrangements, ways of facilitating global roaming and so on). The ITU-R WP8F Group since WRC2000 had number of meetings and all the frequency arrangements have been discussed and up to now. Taking into account all block situations and facilitating aspects of backward compatibility with 2G systems, potential frequency arrangements have been opted within the Draft New Recommendations. Frequency arrangements in the band 806-960 MHz, has two options A1 (824-849 MHz/869-894 MHz with centre gap of 20 MHz and duplex separation of 45 MHz) and A2 (880-915 MHz/925-960 MHz with centre gap of 10 MHz and duplex separation of 45 MHz). Frequency arrangements both in the band 1710-2200 MHz in terms of 6 options and in the band 2.5 GHz can be depicted from reference [10]. The extension band of 2500-2690 MHz in Europe is expected to be available in certain European countries from 2006-2008 onwards.

In the USA, FCC released a document dated 7th. November 2002 in which they confirmed the allocation of 90 MHz spectrum that can be used to provide Advanced Wireless Services (AWS) including services commonly referred to as 3G or IMT2000. The Commission allocated two contiguous 45 MHz frequency bands located at 1710-1755 MHz and 2110-2155 MHz. Both bands are allocated for fixed and mobile wireless services. FCC also proposes licensing and service rules that permit these bands to be used for any service consistent with the bands-fixed and mobile allocations, including the provision of AWS.

The biggest issue to realising B3G systems is to make a sufficient and new radio spectrum available means new, smarter government spectrum policies. Consumer and business users that are hungry for bandwidth, will face a great spectrum famine unless national authorities take some significant measures in revamping their spectrum allocations. The demand for even higher data rates and potential need of wider bandwidths for B3G systems along with the associated new technologies (advanced antenna solutions, guard bands, deployment conditions) will eventually raise questions on spectrum needs. It is a common sense that internationally agreed spectrum bands would encourage the development of systems beyond 3G by facilitating global roaming and reducing equipment cost. For that reason, both WWRF and ITU-R WP8F are working on vision for the B3G systems in order to define the required bandwidth.

Although the studies are still in its infancy, initial estimates reveal that around a 1 GHz of spectrum bandwidth would be required to assure the above facilities. It is already expected that the overall requirement will exceed the GHz. Notwithstanding the imperative to further develop spectrally efficient modulation schemes and frequency re-use techniques, for the longer term, effort must be exerted to encourage considerably increased access to the 5 GHz band for mobile services [11]. Consequently, we can look at 5GHz bands. It is known that unlicensed bands for Radio LAN(RLAN) are also available in 2400-2483.5 MHz, 5150-5350 MHz, 5470-5725 MHz, and 17.1-17.3 GHz. The global usage of 5150-5350 MHz and 5470-5725 MHz for RLAN is the subject of WRC2003.

The 5 GHz spectrum band and the license exempt approach have a considerable potential for any new radio interface compared to the traditional segmented approach for today's individual cellular operators. The WRC2007 is foreseen to consider the spectrum requirements and allocation for either even more additional spectrum for 3G or systems beyond. This spectrum availability is to be targeted at least 5 years before the deployment of matured new wireless systems, i.e., 2010 for systems to be used in the horizon of 2015. The specific agenda item for WRC2007 will be decided at WRC2003 for this issue. However, active partners should carry out necessary research and investigation for novel technologies that results in efficient spectrum usage.

IV. TECHNOLOGICAL CHALLENGES FOR B3G SYSTEMS

A. *Technological Breakthrough*

It is obvious that technological breakthrough can be predicted on a time period of more than ten years as it should be to assess the future mobile B3G systems. New technical solutions will put forward new technology that will in turn focus a growing interest for an evolution of 3G and B3G. Looking at the advances during recent years, we can see already decisive technological progresses that have deeply affected the technological choices and spread the use of radio techniques [9]. We mention a few as follows:

- Progress in processing power and memory size: the well-known Moore's law has been verified for many years and it is not yet sure that this exponential increase will rapidly slow down. It made possible the development of low weight, low cost and high performance portable terminals. It allows to introduce complex and efficient signal processing techniques enabling to use new access, coding or modulation techniques so new systems.
- Progresses in integrated components in particular radio components have been rapid in the recent years opening higher frequencies to general public systems as so expanding the useful spectrum; however new bands are not equivalent to previous bands and bands should be clearly differentiated.
- Software Defined Radio (SDR) provides a concept where functions previously carried out in hardware (generation of transmitted radio signal and tuning of the received radio signal) are performed by software in high-speed digital signal processors. SDR devices can be programmed to transmit and receive on multiple frequency bands using various transmission formats (standards). It has been recognised as one of the most important new technologies for the development of future generation wireless systems.

B. *Current Radio Air-Interfaces and Evolutions*

The choice of radio interface is crucial since it determines not only the fundamental capacity of a mobile radio network, but also how it deals with such issues as interference, multipath propagation, and handover of calls from one base station to another as users move around. Consequently, the choice of radio interface greatly affects system complexity and cost.

To understand what is being developed, and why, it is worthwhile to remember the stated goals of 3G systems, namely support for variable user data rates as high as 2 Mb/s for limited mobility and at least 384 kb/s for a full mobility. In one way or another, all the radio technologies adopted make it possible to adapt the bandwidth on demand [12].

All air interfaces in 3G systems are WCDMA as specified by 3G Partnership Project (3GPP) and CDMA2000 as specified by 3GPP2. Both are based on Direct Sequence CDMA (DS-CDMA) access scheme, in combination with Time Division for TDD based variant. The key features in both systems are quite similar with efficient channel coding with rate matching and multiplexing solutions, transmit and receive diversity, beam forming, link adaptation techniques and shared channels for packet transmissions.

UMTS includes two basic modes, namely Frequency and Time Division duplex (FDD and TDD) that are used for operating with paired and unpaired bands, respectively. The FDD and TDD modes are defined as follows:

- FDD: Uplink and downlink transmissions use two different carriers located in specific frequency bands. Users who are using the same carrier sets are distinguished by different spreading codes.
- TDD: Uplink and downlink transmissions are carried over the same carriers by using synchronized time intervals. Timeslots are divided into transmit and receive parts. Information is transmitted alternately on the uplink and downlink. In addition, users sharing the same timeslots and carrier are multiplexed in CDMA mode.

With TDD it is possible to tune the downlink versus uplink data rate according to traffic asymmetry requirements. This is achieved by setting the switching point of the frame that delimitates the number of time slots allocated to the downlink and uplink.

B.1 Medium Term Air-Interface Evolutions

Considering the present situation, it is important to be able to use efficiently the available spectrum, and provide a certain level of complementarity between the air interfaces. This can be achieved through multi-standard capable architecture and equipment and intelligent multi-standard resource management. These topics are developed in the rest of the paper.

For future evolutions, the new most prominent new techniques that already have been proposed are:

- Other modulations schemes, with possibly increased carrier bandwidth are being considered for the extension bands. One approach currently under study in the 3GPP is OFDM (Orthogonal Frequency Division Multiplexing). Wider carrier bandwidth will allow higher data rates, and better statistical multiplexing in packet mode.
- Improvement of broadcast and multicast services will create some new needs of improved radio resource usage. The techniques involved may cover multicast power control on the downlink, and ARQ, mixing point to point and point to multipoint operation.
- Another highly advanced concept for radiocommunications is the "*Ultra Wideband*" (UWB) technology that is being investigated in the framework of short-range devices for unlicensed operation [13]. The principle is derived from spread spectrum techniques with very wideband dispersion such that energy in unit bandwidth is below the noise level, supposedly eliminating interference and compatibility problems with other services. In other words, UWB systems will occupy a very wide spectrum and be used very efficiently as a countermeasure against the propagation troubles, and also be employed in superimposition over existing classical radiocommunication systems.

It is also worth to mention that the availability of the extension band will have some impacts on the standard definition, including, for example, standalone downlink carriers to improve the downlink throughput. To better fit the traffic evolution requirements, there are also some proposals to have a flexible spectrum organization, with, for example, a tuneable downlink/uplink bandwidth ratio. Another strong tendency is the need for openness to more air interfaces. Standardization bodies such as the 3GPP will have to define networks with a sufficient flexibility to provide a certain "*Openness of the standard to new air-interfaces*" [14].

B.2 Long Term Air-Interface Evolutions

The long term evolutions towards higher data rates (100 Mb/s up to 1 Gb/s), which will be possible with additional spectrum and improved signal processing and waveform definition will mainly be driven by the technology improvements [11] and [15]. Amongst the most important improvements aiming at higher capacity and data rates that can be anticipated, there are:

- Beamforming in the base station, which can provide very significant coverage or capacity improvements (whose actual value depends on the number antennas elements).
- Multiple Input Multiple Output (MIMO) techniques, which seem also very promising to improve the spectrum efficiency. MIMO requires several sufficiently spaced antennas in the terminal and a much higher processing capability that has to be provided by future Very Large Scale Integration (VLSI) technology.
- There is also a significant potential gain achievable with improved signal processing techniques. These techniques include joint detection, improved receiver (for channel estimation and Rake receiver). To reach the optimum gain, they have to be combined with beamforming. This requires of course much higher processing capability.
- Software defined radio as already mentioned in Section IV-A offers also very interesting perspectives to implement multi-band and multi-standard terminals able to follow standard evolutions thanks to software download.
- More generally, there is also a need for higher data rates with extended battery life terminals.

C. Technology Trends towards B3G Systems

Future public mobile radio networks will incorporate a multitude of different air-interface standards, which may have different capabilities and coverage. Depending on the terminal capabilities and user demands with respect to data rate, range, and mobility one of these air interfaces may be used for a specific service that allows for the optimisation of this selection process. As the different access technologies all deploy their own access networks, interworking between the technologies is mainly done via the core network which has only parts of the necessary information needed for the envisaged optimisation available. Moreover, as in this type of interworking several parts of the networks are involved which causes overhead and delay, the frequency of changes of the air interfaces is strongly limited, which further reduce the possible benefit. Therefore, in order to improve the spectral efficiency, it would be beneficial to integrate the air interfaces closer inside a common Radio Access Network (RAN) which allows to do a more efficient air interface selection independent of the core network. So, the boundary between the Core Network (CN) and the RAN may become softer or will even disappear for B3G systems. To allow for a cost effective provision of Internet services, an IP based unified radio access network has to be developed.

This Unified Radio Access network will employ a common control for a multitude of air interfaces and thereby enables the efficient selection of the air interface technology for each of the requested services. The new architecture will use unified IP based mechanisms for similar tasks which simplifies the heterogeneous protocol world, reduces the overhead caused by incompatibilities, enables multistandard radio resource management, allows for seamless mobility across different air interface technologies, and paves the way for the development, integration, and deployment of future air interfaces. These common mechanism include a common radio bearer control as well as a unified RAN mobility management. Moreover, advanced multistandard radio resource management mechanisms for intelligent traffic management and optimised QoS shall be provided. In order to provide seamless mobility between different air interface technologies the system takes care of the QoS of ongoing communication and supports mediation between user application and air interface capabilities.

Our vision is towards a mobile radio access that is transparent for the user and automatically selects the optimal standard and frequency band depending on the actual requirements given by the application and the available resources in the radio network. Starting from this vision, we identified the technologies "*Multistandard RAN architecture (MxRAN)*" and *the "Multistandard*

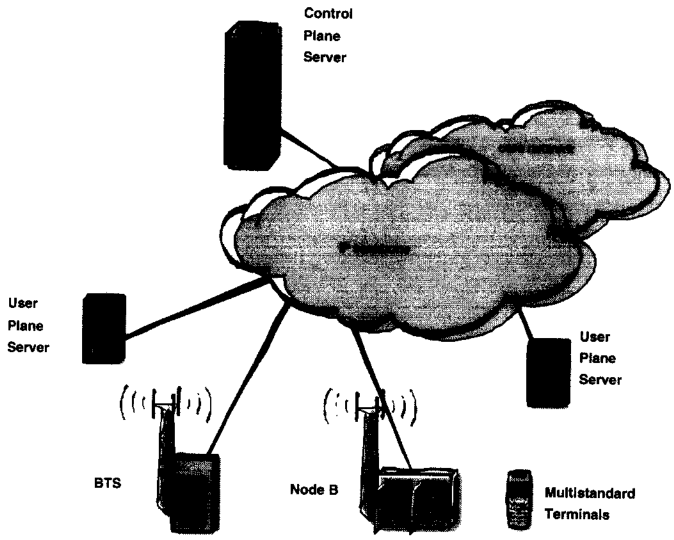

Fig. 3. Distributed MxRAN architecture.

Radio Resource Management (MxRRM)" as the major challenging issues towards a Unified Radio Access network [6]. For an evolution approach in the chapters below we analyse the 3G technology and define ways towards B3G.

C.1 MxRAN Architecture

Today, the RAN for different cellular networks are logically and physically separated networks, both of them deploying their own network elements. Looking at the basic requirements of corresponding network elements and taking into account advances in system and chip design leads to the idea of unifying corresponding network elements of the two standards in a single multistandard network element. Furthermore, it is proposed to further split up today's network elements in smaller parts according to a functional split leading to a RAN system architecture with enhanced flexibility, scalability properties, and redundancy mechanisms as depicted in Fig. 3 [16]. As the base stations are hardly affected by these issues the main focus is put on the Radio Network Controller (RNC) in this paper.

C.1.a Methodology

The radio controllers of today's systems, e.g., the Radio Network Controller (RNC) in UMTS Terrestrial Radio Access Network (UTRAN) or the BSC in GSM/EDGE Radio Access Network (GERAN) are monolithical network element carrying out both control and user plane functions and performing many different and sometimes unrelated functions. The Multistandard RAN architecture aims at splitting the radio network layer functions of a radio controller across several simpler functional entities [17].

In order to define the Multistandard RAN functional architecture an analysis of the different RAN architectures, has been performed. Based on this analysis, a list of atomic functions performed in today's UTRAN/GERAN has been elaborated and each of these atomic functions are assigned to functional entities which were identified following the architectural principles:

- Split of the control and user planes (it has also been adopted in CN Circuit-Switched domain).
- Separation of cell, multi-cell and user related function.

The functional elements can be bundled in different ways which results in different possible network elements and RAN architectures which can be evaluated against the current approach.

C.1.b MxRAN Functional Architecture

Fig. 4 shows the split of the radio controller in different functional entities and the classification of the resulting entities in the control or user plane according to their scope.

For user related functional entities, there exists one instance per user. These functional entities are independent of the topology of the network, i.e., they have no knowledge of cells or their geographical distribution. Furthermore, an instance of these entities is created when a new user connects to the RAN and is deleted when the connection is released. Cell related functional entities have the scope of a single cell, and hence there is one instance of each of these entities per cell.

Finally, there are several functional entities having a multi-cell scope. One instance of such entities is responsible for a certain group of cells. Therefore, they are responsible for a certain geographical area. Fig. 5 shows a functional architecture and not a network reference architecture, i.e., the main functional entities and their logical interconnections have been identified, but it is still possible to bundle several functional entities together in order to reduce the number of external interfaces and reduce the complexity of the architecture.

C.1.c RAN Evolution towards Multistandard RAN

The split of the control and user planes was identified as one of the most important architectural principle in order to implement true multistandard RAN controllers and allow for a more distributed network architecture with enhanced flexibility and scalability properties:

- The processing requirements for the control and user planes are quite different as user plane functions are more demanding and need specific hardware support. The control plane processing is more generic and less demanding and can be implemented in a general purpose machine (server).
- Due to the expected growth in data services there is a strong need to increase the user plane capacity in the network while the control plane capacity will grow just moderately. Such independent scaling has to be supported by the new architecture.

This leads to the idea to define two main multistandard building blocks, a control plane platform and a user plane platform as shown in Fig. 6. These building blocks can be used for a centralised RAN controller where both planes are implemented in a common network element interconnected via an internal interface. In a further evolution both parts could be separated in different networks elements leading to a distributed architecture where control plane and user plane servers are not necessarily co-located and are interconnected via an external interface.

Both platforms run specific applications for the different radio access technologies (in the depicted example UTRAN and

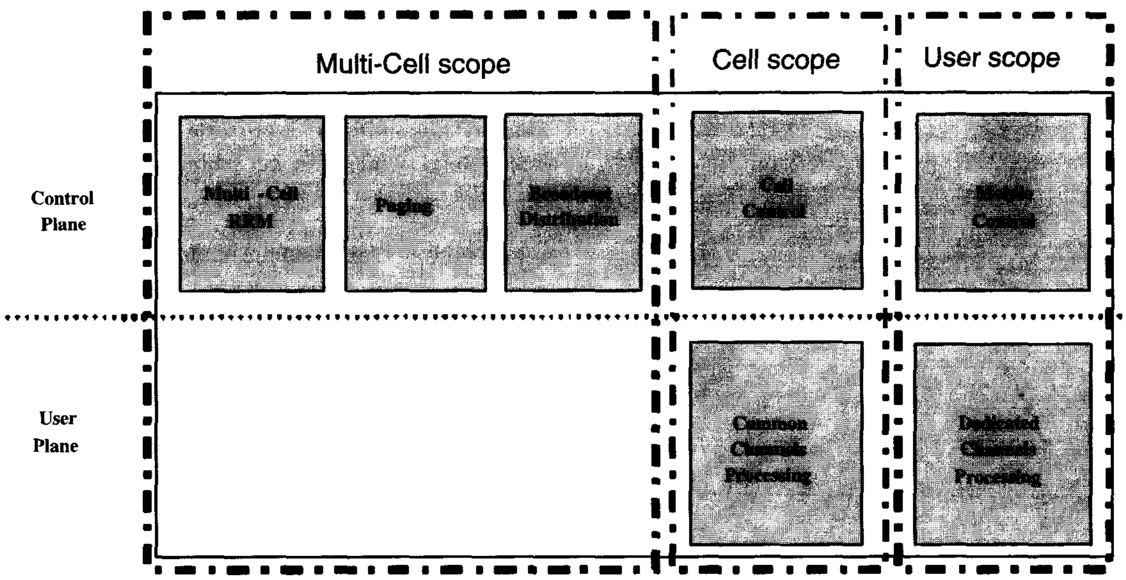

Fig. 4. Split of the RNC in functional entities.

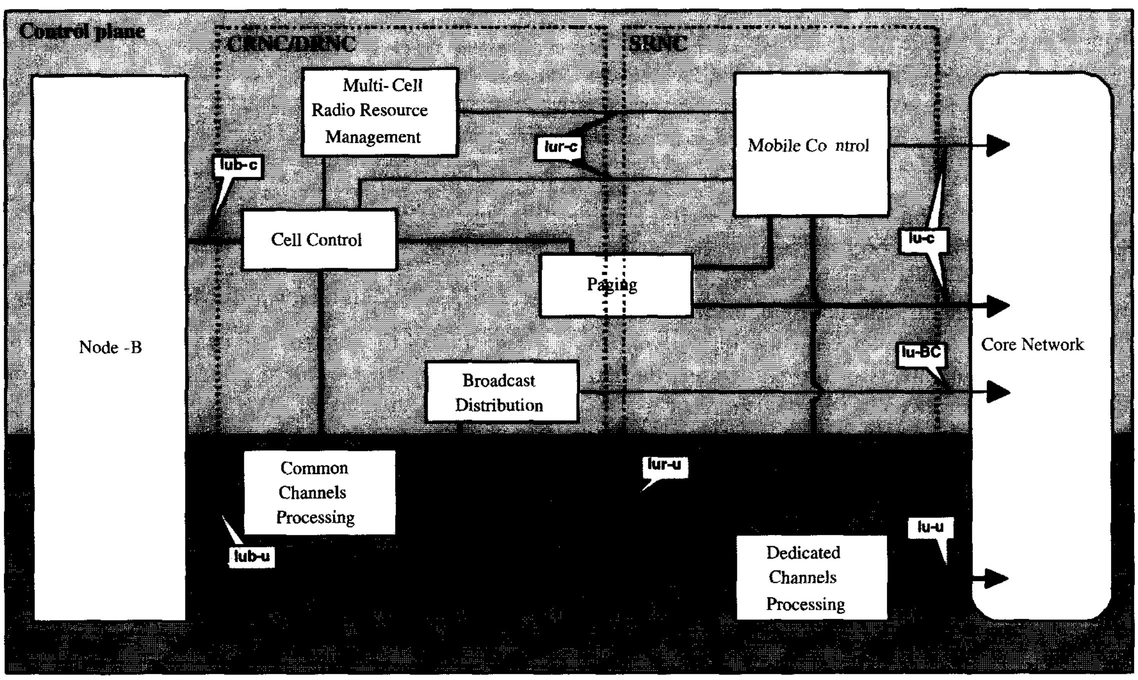

Fig. 5. Multistandard RAN functional architecture and approximate mapping to UTRAN.

GERAN functions) as defined by the specific standards. In addition to this the control plane may also run multistandard applications like the Multistandard Radio Resource Management which is discussed in the following section.

While a centralised RAN controller can provide scalability on module basis the distributed server architecture can additionally provide scalability on network element. Moreover in the distributed approach, new servers may be introduced to support new enhanced demanding features while old servers are reused for legacy services. But, the distributed architecture may potentially lead to an increased delay for control procedures and a more complex Operation/Administration Maintenance (OAM) due to the higher number of network elements. Moreover, a new external interface has to be specified.

C.2 MxRRM Technology

C.2.a Need for MxRRM

The current available cellular networks (UMTS, GSM) contain already means to handover or relocate a connection from one radio access technology to another. However, the handover decision is only taken by the serving system without knowledge of the load in the target system. For this reason requests for handovers and relocations will occur that can not be accepted by the destination cell and consequently will result in dropped

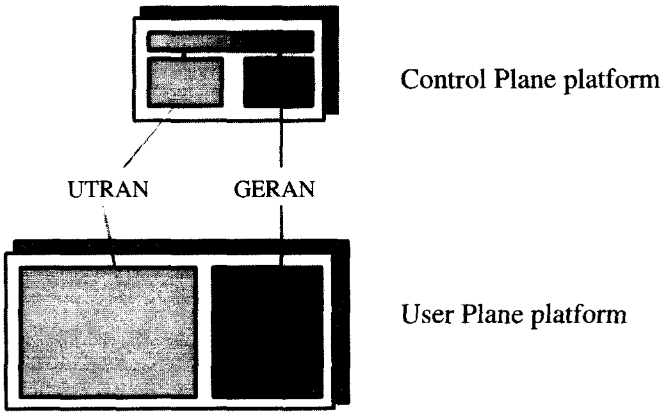

Fig. 6. MxRAN building blocks.

connections.

The setting of the parameters to carry out inter system handovers in a proper way to avoid unbalanced load is already a difficult task and will become even more complex in the future as multiple cells from different Radio Access Technologies (RAT) will overlap and multiple layers (macro, micro, and pico-cells) will be available. In such an environment, a true Multistandard RAN must be able to co-ordinate the use of the different cells belonging to several standards.

The decision for the best air interface for each service will be provided by a new function within the network, the Multistandard Radio Resource Management (MxRRM).

C.2.b Basic principles

The new MxRRM functional entity has to collect information from the air interfaces and the terminals. Obviously, the most important data would be the information about the available resources and the load of the different air interfaces as well as the required QoS of the application. Furthermore several additional information (e.g., velocity of mobiles, coverage of cells....) may be advantageous to get good decisions by MxRRM. With the data derived from air interfaces and mobiles the MxRRM decides on call admission, handovers or probably also some other RRM tasks (e.g., congestion control). The basic principles of this new MxRRM functionality is depicted in Fig. 7 [6].

With the help of this RRM entity an optimised resource usage within the RANs can be achieved. In particular a load balancing is possible that provides a distribution of traffic among different RATs and an improved overload control as well as an intelligent traffic management in hierarchical cell structures. The providers take advantage of MxRRM because they can offer a more reliable service to their users and can increase their revenues from the investments into their RANs and their licences because of a higher average throughput. The benefit of MxRRM for the user is an optimised QoS since lower blocking and dropping as well as a minimised number of service degradations in case of handover can be achieved due to knowledge of available resources by the MxRRM.

C.2.c Functional Architecture

To investigate the MxRRM functionality the Resource Management (RM) within an access network will be divided into two functional entities:

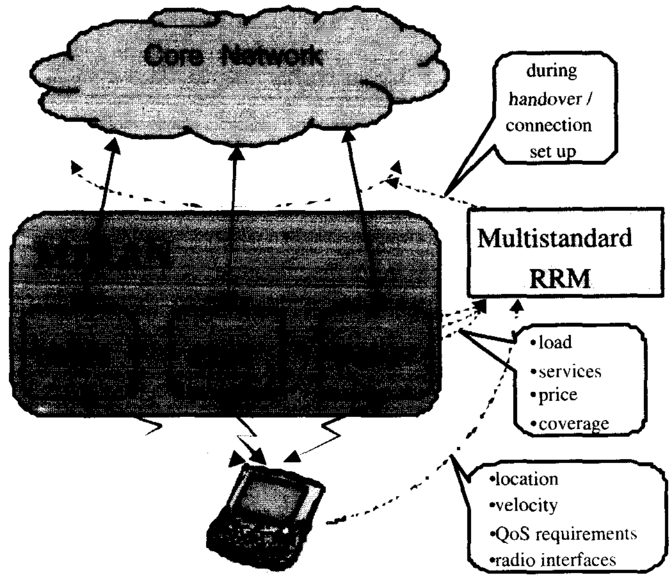

Fig. 7. Multistandard RRM (MxRRM) concept.

- *RRM that is only responsible for the resources of one RAT and*
- *MxRRM that co-ordinates the RM over multiple RATs of a multistandard network.*

In the following, these entities are discussed from a functional point of view. For their mapping to network elements several approaches are feasible and need to be investigated in a second step.

Since for each RAT own resource management mechanisms are defined one basic decision that has to be taken is, which tasks have to be part of the particular RRM i.e., are carried out without any knowledge of other RATs and which tasks have to be contained within the MxRRM i.e., they are carried out with the use of knowledge of load and capacity data of other available RATs. An extreme solution that is conceivable is that the MxRRM functionality carries out all decisions that have been taken to manage the available air interface resources. In this scenario the MxRRM functionality has to get very detailed and actual information about the current state of different air interfaces. Nevertheless with an MxRRM that does the whole resource management of all layers one entity exists that has the full information of the network including all air interfaces. Such a functionality is in principle able to optimise the network to the maximum quality since it is fully informed about the entire network - this solution is a theoretical limit but seems to be rarely applicable in practise in particular in the near future. In case the MxRRM has only a limited view about the resources and load within the network some information can not be taken into account to optimise the use of resources and one gets therefore sub-optimal solutions. It has to be decided which tasks have to be done by RRM and which by MxRRM to get near optimum throughput with reduced signalling load and less time critical signalling. One example of a radio resource management task where only limited advantage form the knowledge of other air interfaces is expected is the power control with the CDMA air interface. Therefore, it is not expected to get much better results if the power control of the UMTS air interface is carried out within the MxRRM functionality. Another point is, that power control is a time critical task so that it is necessary to do the power control in close distance to the Node B to have lower transmission delay for the power control commands. Another task of the resource management of cellular access networks is to decide about handovers of dedicated channels. This is seen as the main task of MxRRM required to achieve better throughput of the networks and to achieve better QoS for the user. This task has to be done by MxRRM since only the MxRRM has a global view of the network and is able to find out whether inter system handovers will succeed. Congestion control is a further tasks of the resource management which should be moved to MxRRM. Even if the congestion control of the single layer is done autonomously by RRM a procedure is required to enable MxRRM to reduce load in a controlled manner if problems occur in certain areas that can not be solved by intersystem handovers. This is a kind of MxRRM load control. For this function we need a procedure to drop certain connections on demand of MxRRM. The aim of this function is that congestion control of the single air interfaces becomes a rarity.

V. CONCLUSIONS

In this article, we aim to familiarise our readers to the evolution of 3G systems towards B3G systems. Therefore, we try to find potential answers first, to the reason "***why***" we need a further evolution of 3G towards B3G systems, secondly, in "***which***" time period we may deploy and the third, "***what***" the new system (B3G) will look like.

We also summarise the drive toward universal wireless communication and services to be provided by new B3G systems and describe some of the technologies that provide a basis for the evolution toward next generation wireless. Moreover, we highlight potential technologies such as Software Defined Radio and UWB techniques in the framework of medium term and long term air-interface evolutions. Furthermore, we present in details "*Heterogeneous wireless access*" technologies. An important issue here, is the handling of seamless mobility across different air interfaces in order to offer the user a homogenous access to services. This requires that the system takes into account the QoS of ongoing calls and allows for the mediation between user application and air interface capabilities. Given that the difficulties encountered nowadays, to master end-to-end QoS in the current 3G infrastructure, it is evident that the above reasoning is one of the key challenges in the heterogeneous wireless access. Nevertheless, we believe that the Unified Radio access approach will provide the platform for integration of current 3G and future air-interfaces to build the public mobile radio network beyond 3G.

As a concluding remark, we can state that next generation wireless systems (B3G) are to a large extent in the research stage and we do not as yet have a common definition of what B3G is. However, one of the key factors for B3G systems to be more attractive will be the data rate, i.e., 100 Mb/s in full mobility applications while around 1Gb/s in low mobility applications. Such high data rates will require sophisticated potential technologies as mentioned in this contribution. Finally, it is evident that B3G will co-exist with 3G systems and "Heterogeneous Wireless Access" technologies will facilitate such a co-existence in the long-term.

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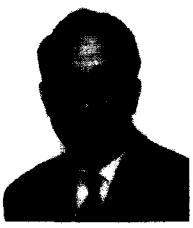
REFERENCES

[1] A. Lightman, *Brave New Unwired world - Digital Big Bang and the Infinite Internet*, John Wiley & Sons, New York, USA, 2002.
[2] V. Kumar, "Wireless communications beyond 3G," *Alcatel Telecom Review*, 2001, Q1-Find your way with 3G, pp. 28–32, Mar. 2001.
[3] R. Berezdivin *et al.*, "Next generation wireless communications concepts and technologies," *IEEE Commun. Mag.*, vol. 40, no. 3, pp. 108–116, Mar. 2002.
[4] H. Honkasalo *et al.*, "WCDMA and WLAN for 3G and beyond," *IEEE Wireless Commun.*, vol. 9, no. 2, pp. 14–18, Apr. 2002.
[5] M. Frodigh, "Future generation wireless networks," *IEEE Trans. Pers. Commun.*, vol. 8, no. 5, pp. 10–17, Oct. 2001.
[6] M. Hildebrand *et al.*, "Location based radio resource management in multistandard wireless network environment," *CEC IST Mobile & Wireless Telecommun.* Summit 2002, Thessaloniki, Greece, pp .458–462, June 2002.
[7] ITU-R WP8F, "Vision group preliminary draft new recommendations (PDNR)," 8F/TEMP/311 and 316, 8th WP8F Meeting, Ottawa, Canada, June 2002.
[8] Telecompetition Report on "The world-wide mobility - 2001," Available at http://www.telecompetition.com.
[9] C. Evci and B. Fino, "Spectrum management, pricing and efficiency control in broadband wireless communications," *IEEE Proc.*, vol. 89, no. 1, pp. 105–115, Jan. 2001.
[10] ITU-R, WP8F, Spectrum Group Documents, 8F/TEMP/289, Ottawa, Canada, June 2002.
[11] K. Pehkonen *et al.*, "Key Technologies and concepts for beyond 3G networks," *Proc. SPIE conf. Wireless and Mobile Commun.*, vol. 4586, Beijing, China, pp. 43–57, Nov. 2001.
[12] P. Sehier *et al.*, "Standardization of 3G mobile systems," *Alcatel Telecom Review, 2001*, Q1-Find your way with 3G, pp. 11–18, Mar. 2001.
[13] "Ultra wideband (UWB) technology," Available at http://www.time-domain.com.
[14] 3rd. generation Partnership Project: Technical Specification Group Radio Access Network: Improvements of RRM across RNS and RNS/BSS (Release 5), 3GPP TR 25.881, V2.0.0.
[15] W. Mohr and W. Konhauser, "Access network evolution beyond third generation mobile communications," *IEEE Commum. Mag.*, pp. 122–133, Dec. 2000.
[16] Mobile Wireless Internet Forum, "OpenRAN architecture in 3rd. generation mobile systems," Technical Report, Sept. 2001, available at http://www.mwif.org.
[17] J. Kempf and P. Yegani, "OpenRAN: A new architecture for mobile wireless internet radio access networks," *IEEE Commun. Mag.*, vol. 40, no. 5, pp. 118–123, May 2002.



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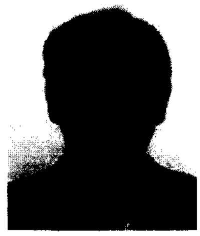

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