Next Generation Mobile Systems

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Abstract— **Next generation mobile systems are being defined at the ITU as IMT-Advanced. They will probably appear as an evolution of WiMAX 802.16e and LTE, which are currently under standardization as 802.16m and LTE-Advanced. These systems will require large chunks of spectrum, with both FDD and TDD deployment. We expect the use of all the IMT bands designated by ITU for these systems with increased flexibility in spectrum management and access to spectrum. Prime spectrum for capacity is 2500-2690 MHz, and spectrum for coverage should be obtained from the "digital dividend" and GSM900 spectrum refarming. In the Republic of Macedonia as a first sign of a more flexible spectrum management the Agency of Electronic Coomunications (National Regulator Authority) has approved of WiMAX spectrum swapping.**

Keywords— **4G, IMT-Advanced, WiMAX, LTE, IMT bands, digital dividend, spectrum refarming, flexible spectrum management.**

I. Introduction

Today society is becoming more and more dependent on the services provided by internet. Future e-society will include a number of e-services, such as e-government, e-business, e-education, e-health, e-citizens. It is possible to use internet for voice and television services as well (VoIP, internet television). Finally, we should not forget the use of internet for entertainment, such as downloading/streaming audio and video files, and gaming. All these services require high transmission rates, so the need of broadband internet arises. Broadband internet could be provided by wired connection (ADSL, cable, fiber) and wireless connection. Although FTTH (fiber to the home) might be the ultimate goal to achieve, wireless broadband systems are becoming a strong competitor to wired systems (including fiber systems) in terms of both transmission rates and quality.

The most obvious advantage of mobile broadband is the fact that it is quite convenient to use. With mobile broadband, a person can connect to the internet from any location. Another big advantage of mobile broadband is communicating while moving. Mobile broadband has the potential to provide coverage in rural and sparsely populated areas and help bridge the "digital divide".

Future mobile systems will provide bit rates of 100 Mbit/s while moving and 1 Gbit/s in low mobility scenarios. ITU is in the process of defining next generation mobile systems - IMT-Advanced. Two strongest candidates for IMT-Advanced are the evolutions of WiMAX and LTE (Long Term Evolution). Here we study these two systems and their evolutions. We also discuss the frequency bands planned for these systems, focusing on the bands under 1 GHz, currently used by other systems and on the ways of freeing them up (spectrum refarming, "digital dividend").

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We start in Section II with the overview of the state of the art of current mobile broadband systems - 3G-HSPA and WiMAX, and continue in Section III with the description of future mobile broadband systems. In Section IV we cover the bands designated for these systems. We discuss the issue of flexible spectrum management in Section V. In Section VI we give a view from Republic of Macedonia concerning the introduction of mobile broadband systems.

II. State of the Art of Mobile Broadband: 3G-HSPA, WiMAX

The 3rd Generation Partnership Project (3GPP) is a collaboration that brings together a number of telecommunications standards bodies. The USA, Europe, Japan, South Korea and China jointly formed the 3GPP. At present, it has more than 400 member companies and institutions. The 3GPP defines GSM and WCDMA specifications for a complete mobile system, including terminal aspects, radio access networks, core networks, and parts of the service network. Standardization bodies in each world region have a mandate to take the output from the 3GPP and publish it in their region as formal standards. 3GPP specifications are structured in releases. All new releases are backward-compatible with previous releases.

The development of the 3GPP technology track (GSM/WCDMA/HSPA) has been spectacular. WCDMA 3GPP Release 99 provided data rates of 384kbps for wide-area coverage. However, higher data rates were soon required as the use of packet data services increased and new services were introduced.

Among other things, WCDMA 3GPP Release 5 extended the specification with a new downlink transport channel, the high-speed downlink shared channel, which enhanced support for high-performance packet-data applications. Compared with Release 99, the enhanced downlink gave a considerable increase in capacity, significantly reduced latency and provided downlink data rates of up to 14Mbps. These enhancements, commonly referred to as HSDPA (high-speed downlink packet access), were a first step in the evolution of WCDMA. Although a great deal of traffic is downlink-oriented, several applications also benefit from an improved uplink. The key enhancement in WCDMA 3GPP Release 6 was a new transport channel in the uplink, HSUPA (high-speed uplink packet access), which improved throughput, reduced latency and increased capacity. HSUPA provides data rates of up to 5.8Mbps. The combination of HSDPA and HSUPA is called HSPA (high-speed packet access). 3GPP Release 7 introduced HSPA evolution (also called HSPA+), which supports MIMO, 64QAM in the downlink, and 16QAM in the uplink, to further boost the peak data rate and capacity. HSPA evolution supports data rates of up to 42Mbps in

the downlink and 11.5Mbps in the uplink. LTE (long-term evolution), currently being specified by 3GPP for Release 8 (scheduled for completion at the end of 2008), introduces OFDM/OFDMA in the downlink and single-carrier FDMA (SC-FDMA) in the uplink. LTE supports very high data rates, exceeding 300Mbps in the downlink and 80Mbps in the uplink. LTE will support operation in both paired and unpaired spectrum (FDD and TDD) using channel bandwidths of 1.25 MHz up to at least 20MHz.

In August 2008 Qualcomm Inc. has completed the world's first data call using HSPA+ technology. The call achieved a data transfer rate of more than 20Mbit/s in a 5MHz channel.

The goals of HSPA+ are to:

- Exploit the full potential of a CDMA approach before moving to an OFDM platform in 3GPP LTE.
- Achieve performance comparable to LTE in 5 MHz of spectrum.
- Provide smooth interworking between HSPA+ and LTE that facilitates operation of both technologies. As such, operators may choose to leverage the SAE planned for LTE.
- Allow operation in a packet-only mode for both voice and data.
- Be backward compatible with previous systems while incurring no performance degradation with either earlier or newer devices.
- Facilitate migration from current HSPA infrastructure to HSPA+ infrastructure.

According to GSMA (GSM Association) statistics, in the second quarter of 2008, in the whole world, there were a total of 3,665,389,343 mobile subscribers, out of which 2,961,292,242 GSM subcribers (80.79%), 216,434,662 WCDMA subcribers (5.90%), and 43,416,405 WCDMA HSPA subscribers (1.18%).

The IEEE 802.16 Working Group on broadband wireless access (BWA) standards, which was established by the IEEE Standards Board in 1999, prepared the formal specifications for broadband wireless metropolitan area networks (WirelessMAN). IEEE 802.16-2004 (also called 802.16d) provides support for non-line of sight (NLOS) and indoor end-user terminals for fixed wireless broadband (fixed WiMAX). In 2005, the standard was amended (IEEE 802.16-2005 or 802.16e) adding support for data mobility. IEEE 802.16e or Mobile WiMAX improves on the modulation schemes used in the original (Fixed) WiMAX standard by introducing SOFDMA (scalable orthogonal frequency-division multiple access), which enables using different channel banwidths, by changing the number of subcarriers. The system profile in IEEE 802.16e-2005 is not backward compatible with the Fixed WiMAX system profile.

The charter of the WiMAX Forum, which has more than 400 members, is to promote and certify the compatibility and interoperability of broadband wireless access equipment that conforms to IEEE 802.16 and the ETSI HiperMAN standard. The WiMAX Forum thus defines and conducts conformance and interoperability testing to ensure that different vendor systems work seamlessly with each other. WiMAX certification profiles specify characteristics including spectrum band, duplexing and channelization. Several profiles exist for Fixed and Mobile WiMAX.

Because IEEE 802.16 standardization only covers basic connectivity up to the media access (MAC) level, the WiMAX Forum also addresses network architecture issues for Mobile WiMAX networks. The focus of the first network architecture specification (Release 1.0) is on delivering a wireless Internet service with mobility. Release 1.5 adds support for telecom-grade mobile services, supporting full IMS interworking, carrier-grade VoIP, broadcast applications, such as mobile TV, and over-the-air provisioning.

BWA/WiMAX subscribers worldwide reached 2.3 million in Q2 2008 - a 19% growth over the first quarter and a 70% increase over Q2 2007, according to the 5th issue of the WiMAXCounts Quarterly Report from Maravedis (http://www.maravedis-bwa.com). "Of the 264 operators tracked in WiMAXCounts, approximately 50% of them are providing HIS (High Speed Internet) services only. The remaining percentage corresponds to operators that are offering different applications, such as VoIP, Video, VPN, in addition to HIS. We expect however double/triple play to become the norm in the next two years" said Robert Syputa, Maravedis Partner and Senior Analyst.

The first national fixed-WiMAX rollout in the 3.5GHz range was carried out by Wateen Telecom in Pakistan. However, the world's first large scale mobile WiMAX deployment is due in the US. This is the joint venture between Sprint Nextel Corp. and Clearwire Corp. and it is expected to reach 120 million to 140 million people in the US by the end of 2010.

The HSPA and Mobile WiMAX technologies have been designed for high-speed packet-data services. They feature similar technology enablers, including dynamic scheduling, link adaptation, H-ARQ (Hybrid Automatic Repeat Request) with soft combining, multiple-level QoS, and advanced antenna systems. Notwithstanding, their performance differs due to differences in the physical layer signal format, duplex scheme, handover mechanism, and operating frequency bands.

III. Candidates for Future Mobile Systems

There is a lot of controversy as to what is a 4G mobile system. WiMAX proponents call WiMAX a 4G technology, mobile vendors and operators are inclined to consider the evolution of current mobile systems as 4G systems. Most probably, 4G will emerge as the evolution of LTE and/or WiMAX. Although LTE is still in the standardization process (WiMAX is already in the market), there are already evolutions of both systems: LTE-Advanced and WiMAX 2.0 (WiMAX forum certification of IEEE 802.16m).

UMB (Ultra Mobile Broadband) is the brand name for the project within 3GPP2 (3rd Generation Partnership Project 2) to improve the CDMA2000 mobile phone standard for next generation applications and requirements. The system is based upon Internet (TCP/IP) networking technologies running over a next generation radio system, with peak rates of up to 280 Mbit/s. Its designers intend

for the system to be more efficient and capable of providing more services than the technologies it replaces. However, commercialization is unlikely as Qualcomm, its main developer, 3GPP2 and major CDMA2000 carriers are concentrating on LTE instead.

The ITU's IMT-2000 standard, has been updated an average of once a year since its original approval in May 2000. The original document included WCDMA, CDMA2000, TD-CDMA and TD-SCDMA, EDGE, and DECT. Recently, OFDMA technology was added to IMT-2000, as IMT-2000 OFDMA TDD WMAN (a specific profile developed by the WiMAXforum based on IEEE 802.16e). Currently, ITU-R is in the process of defining IMT-Advanced, but, the standards body has backed away from the phrase 4G. Notice that the OFDMA additions to IMT-2000 (IEEE 802.20 and LTE will also become part of IMT-2000) are considered as 4G by some, and, thus, the distinctions between IMT-2000 and IMT-Advanced may blur. 4G technologies will certainly find their way into IMT-Advanced, but not all 4G standards may end up in IMT-Advanced. Likewise, IMT-Advanced may include non-4G technologies. To announce the current stage of the process for IMT-Advanced, ITU-R has issued a Circular Letter (CL) to invite submission of candidate Radio Interface Technologies (RITs) or a set of RITs (SRITs) for IMT-Advanced. The key features of IMT-Advanced delineated in the CL are:

- a high degree of commonality of functionality worldwide while retaining the flexibility to support a wide range of services and applications in a cost efficient manner;
- compatibility of services within IMT and with fixed networks;
- capability of interworking with other radio access systems;
- high quality mobile services;
- user equipment suitable for worldwide use;
- user-friendly applications, services and equipment;
- worldwide roaming capability; and
- enhanced peak data rates to support advanced services and applications (100 Mbit/s for high and 1 Gbit/s for low mobility were established as targets for research).

One thing that everyone agrees upon is that future mobile systems will be OFDM based. We next consider LTE, LTE-Advanced and IEEE 802.16m.

LTE (Long Term Evolution) describes the latest standardization work by 3GPP in the mobile network technology tree previously realized the GSM/EDGE and UMTS/HSxPA network technologies that now account for over 85% of all mobile subscribers. In this latest standardization work which started in late 2004, the 3GPP defines a set of high level requirements (new high-speed Radio Access method) for mobile communications systems to compete with other latest cellular broadband technologies, particularly WiMAX.

Unlike UMTS, which is based on Wideband Code Division Multiple Access (W-CDMA) technology, LTE is based on OFDMA and in this regard, LTE is similar in concept to Mobile WiMAX, although the systems operate with different frame structures, sub-carrier spacing, and channel bandwidths. A notable feature of LTE is a new, OFDM-derived modulation format for the uplink. This format, called Single Carrier Frequency Division Multiple Access (SC-FDMA), combines the low peak-to-average power ratio (PAPR) of single-carrier systems with the multi-path resistance and flexible sub-carrier frequency allocation offered by OFDMA.

In preparation for further increasing user demands and tougher competition from new radio access technologies, LTE is enhanced with a new radio access technique called Evolved UMTS Terrestrial Radio Access Network (E-UTRAN). Via this technology LTE is expected to improve end-user throughput, increase sector capacity, reduce user plane latency, and consequently offer superior user experience with full mobility.

E-UTRAN has the following features:

- Flexible bandwidth usage with 1.25 MHz to 20 MHz bandwidths. By comparison, W-CDMA uses fixed size 5 MHz chunks of spectrum.
- Operation in both FDD and TDD modes
- Increased spectral efficiency at 2-4 times more than in 3GPP(HSPA) release 6.
- Peak downlink rates of 326.4 Mbit/s for 4x4 antennas, 172.8 Mbit/s for 2x2 antennas, 100 Mbit/s for single antenna system, for every 20 MHz of spectrum (with 64 QAM).
- Peak uplink rates of 86.4 Mbit/s for every 20 MHz of spectrum (with 64 QAM).
- End-user latency < 10 ms (round-trip time between user equipment and the base station).
- Control plane latency < 100 ms (transition time from inactive to active).

To support LTE a new core is required, as specified by the SAE (System Architecture Evolution). In the standards community the names have now become E-UTRAN for LTE, and EPC (Evolved Packet Core) for SAE. The complete packet system consisting of the E-UTRAN and the EPC is called the Evolved Packet System (EPS). SAE/EPC is defined by 3GPP in Release 8 as an entirely new core network with a flatter all-IP architecture enabling a higher-data-rate, lower-latency packet-optimized system that supports multiple radio-access technologies, focusing on the packet-switched domain, with the assumption that the system will support all services, including voice, in this domain.

LTE standardization within the 3GPP is strongly supported by the GSMA. Founded in 1987, GSMA is a global trade association representing more than 750 GSM mobile phone operators across 218 territories and countries of the world. In addition, more than 180 manufacturers and suppliers support the Association's initiatives as associate members.

In May 2007, a group of telecom technology manufacturers and network operators comprised of Alcatel-Lucent, Ericsson, France Telecom/Orange, Nokia, Nokia Siemens Networks, Nortel, T-Mobile, and Vodafone have announced a joint initiative aimed at driving forward the realisation of the next-generation of high performance mobile broad-

band networks based on 3GPP Release 8 LTE/SAE specifications. LTE is already testing, first products are expected in 2009-2010, widespread deployment expected 2012.

In February 2007, Ericsson demonstrated for the first time in the world LTE with bit rates up to 144 Mbit/s, and in September 2007, NTT DoCoMo demonstrated LTE data rates of 200 Mbit/s. In April 2008, LG and Nortel demonstrated LTE data rates of 50 Mbit/s while travelling at 110 km/h. Researchers at Nokia Siemens Networks and Heinrich Hertz Institut have demonstrated LTE with 100 Mbit/s Uplink transfer speeds. On September 18, 2008, Mobile operator T-Mobile and Nortel Networks achieved data rates of up to 170 Mbit/s for downloads and up to 50 Mbit/s for uploads in a car in range of three cell sites on a highway in Bonn, Germany at an average speed of 67 km/h.

In October 2008 Nokia Siemens Networks announced that, by the end of 2008, it will be delivering the new LTE-ready hardware to more than 10 major mobile operators in Europe, Asia and North America.

The specifications of the 3GPP Release 8 standard are assumed to complete at the end of 2008. Obviously the finalization of the 3GPP Release 8 will further progress the market interest in commercial deployment of LTE. The 3GPP Release 8 will compile the completion of 3GPP Release 7 HSPA+ features, voice over HSPA and EPC specification and Common IP Multimedia Subsystem (IMS).

LTE does not meet the requirements for IMT-Advanced such as peak data rates up to 1Gbps. The mobile communication industry and standardisation organisations have therefore started to work on 4G access technologies such as LTE-Advanced. At a workshop in April 2008 in China 3GPP agreed the plans for future work on LTE. A first set of 3GPP requiremens on LTE Advanced has been approved in June 2008. Besides the peak data rate 1Gbit/s that fully supports the 4G requirements as defined by the ITU-R, it also targets faster switching between power states and improved performance at the cell edge. Detailed proposals are being studied within the working groups.

The proposals could roughly be categorized into:

- Various concepts for Relay Nodes
- UE Dual TX antenna solutions for SU-MIMO (single user MIMO) and MU-MIMO (multi user MIMO)
- Scalable system bandwidth exceeding 20 MHz, potentially up to 100MHz
- Local area optimization of air interface
- Nomadic / Local Area network and mobility solutions
- Flexible Spectrum Usage
- Cognitive Radio
- Automatic and autonomous network configuration and operation
- Enhanced precoding and forward error correction
- Interference management and suppression
- Asymmetric bandwidth assignment for FDD
- Hybrid OFDMA and SC-FDMA in uplink
- UL/DL inter eNB (evolved node B) coordinated MIMO

Meanwhile, the IEEE released earlier this year a draft system description document for next-generation WiMAX 802.16m, which will be the group's IMT-Advanced technology proposal. "802.16m should meet the requirements of IMT-Advanced and be backwards compatible with 802.16e," says Roger Marks, chair of the IEEE 802.16 work group and a senior vice president at NextWave Wireless Inc. "We want 802.16m approved and completely finished by end of 2009." The following are some of the key enhancements expected in 802.16m:

- higher spectrum efficiency through more advanced and higher-order MIMO solutions, including multiuser MIMO as well as lower MAC and PHY overhead
- higher peak and user data rates using wider-band carriers (including 20 MHz and higher) and multicarrier aggregation
- enhanced coverage in high interference environments with improved preamble and control channel
- lower latency through faster MAC/signaling
- support for higher mobility through a faster feedback mechanism and link adaptation
- flexible spectrum deployments (both FDD and TDD support in contiguous and non-contiguous bands)
- optimizations for improved interworking and coexistence with other access technologies such as 3G systems, WiFi, and Bluetooth
- support for integrated multihop relay and femtocells
- improved power saving operation

Some vendors are starting to say that it's time to end the WiMAX versus LTE standards battle and work together. At the Next Generation Networks & Basestations Conference in Bath, U.K. in April 2008, Alcatel-Lucent in a presentation on TDD (time division duplex) mode for LTE suggested there may be an opportunity to converge LTE TDD and WiMAX TDD in the new IMT-Advanced standard. The 3GPP organization says that there is nothing official on the table being discussed about merging certain elements of LTE and WiMAX technologies for IMT-Advanced, but it could be a possibility. "LTE-Advanced is a new piece of work and there is a possibility to consider harmonization with other technologies," says Adrian Scrase, 3GPP project coordination group secretary. "But it's rather early days for LTE-Advanced." Scrase notes that any idea of joining forces with WiMAX would have to be driven by 3GPP members. "It could start at a political level, but if there's no consensus at the industrial level, then it doesn't make sense." At the IEEE, they see the potential to merge too. "Certainly, there are possibilities," says Marks. "An awful lot of participants in these standards projects are the same. In principle, one would expect similar decisions. But because of the different politics and cultures, they end up with different decisions. IMT-Advanced as a process could help to stimulate some kind of consensus development."

A few years ago the IEEE 802.20 broadband wireless technology was considered a serious rival to mobile WiMAX, and 3G mobile broadband, but it was given up for dead thanks to a dysfunctional IEEE working group. After renewed efforts, on 12 June 2008, the IEEE has approved the standard. The standard specifies physical and medium

access control layers of an air interface for interoperable mobile broadband wireless access systems, operating in licensed bands below 3.5 GHz, optimized for IP-data transport, with peak data rates per user in excess of 1 Mbps, and speed up to 250 Km/h. The standard includes an OFDM wideband mode and a 625kHz-multicarrier mode. TDD is supported by both the 625kHz-MC mode and the OFDM wideband mode; FDD is supported by the OFDM wideband mode. The wideband mode is OFDMA based, although a portion of the uplink signaling occurs over a CDMA. The 625 kHz mode is uniquely designed around multiple antennas with spatial processing and SDMA.

A. A View from the Operators

There is an ongoing initiative by a group of leading mobile operators, called the NGMN (Next Generation Mobile Networks) project, which is to provide a vision for technology evolution beyond 3G for the competitive delivery of broadband wireless services to increase further end-customer benefits. The objective is to establish clear performance targets, fundamental recommendations and deployment scenarios for a future wide area mobile broadband network, and to make sure that its price/performance is competitive with alternative technologies. This initiative intends to complement and support the work within standardization bodies by providing a coherent view of what the operator community is going to require in the decade beyond 2010. The target architecture is based around a packet-switched core, together with a new radio access technology.

The founding partners of NGNM are China Mobile, NTT Docomo, Sprint Nextel, Vodafone Group, KPN Mobile, Orange, T-Mobile.

The term "NGMN" is technology-agnostic and does not refer to one specific technology or technical standard, but to a range of technologies and standards with certain minimum characteristics.

Key characteristics and requirements of NGMN technologies and networks are:

- Peak data rates in the downlink beyond 100 Mbit/s (bigger than 40 Mbit/s cell average);
- Peak data rates in the uplink beyond 50 Mbit/s;
- Spectrum efficiency and cell throughput (capacity) 3 - 5 times better than 3G/HSPA and CDMA-2000/EVDO;
- Low latencies (round-trip times) of 20 - 30 ms end-to-end;
- Flat All-IP network architecture, with open interfaces, legacy interworking, optimised routing, and always-on support;
- Seamless mobility in indoor, pico/micro-cellular, metropolitan and wide-area deployment scenarios;
- Easy and cost-efficient network deployment leveraging advanced self-organisation, self-configuration and self-optimisation techniques;
- Flexible allocation of radio channel bandwidths in the range between 1.25 MHz and 20 MHz, utilising FDD and/or TDD duplex modes;
- Operation in a wide range of frequency bands between 400 MHz and 5 GHz taking into account the ITU spectrum identified for IMT-2000 and IMT-Advanced systems;
- High-performance, attractive, and affordable end-user devices.

NGMN does not preclude the use of a channel bandwidth larger than 20 MHz in the future if frequency allocations allow this. Thus NGMN makes already provision towards IMT-Advanced, which will support ultra-high downlink data rates up to 1 Gbit/s in a low mobility environment.

Recently, NGMN has endorsed LTE as the next generation mobile broadband network. That was the reason for Sprint to quit NGMN in July 2008. NGMN declared that it would assess WiMAX again in its next iteration, 802.16m.

The question arises as to which technology of WiMAX or LTE will ultimately prevail? It is arguable that LTE is more "risk-free" than WiMAX because it will run on an evolution of existing mobile infrastructure. Also, mobile operators will be able to use their experience from current 3G and HSDPA networks to carry out the incremental fine-tuning necessary to ensure that the rollout of LTE will deliver on user expectations.

But, LTE is still perhaps two years from being ready whereas mobile WiMAX equipment has already entered the deployment phase. Therefore, some operators may take the view that waiting for LTE would mean a loss of potential subscribers perhaps attainable by moving to WiMAX now. Sprint Nextel Corp. opened its new wireless network to customers in Baltimore on October 6st 2008, offering both home Internet service and "on-the-go" service for laptops. It's the first commercial network in US to use WiMAX technology for mobile customers, and provides download rates of 2 to 4 Mbps.

Although WiMAX has a head start advantage, most of the mobile vendors and operators are already in the LTE camp and backing up this technology.

Some of the operators may decide to use both LTE and WiMAX. As Sprint Nextel is showing in the US, the real estate occupied by an operator's current base stations can also be used to site new WiMAX base stations. Then the strategy could be that LTE is used to support mobile broadband users and WiMAX to support fixed or lower-mobility broadband users. AT&T, which focuses on LTE deployment, is considering WiMAX as a rural DSL replacement.

Many devices of the future will ship with both LTE and WiMAX capability, meaning full compatibility across both technologies. Consumers will probably not even know which particular technology is delivering high speed data to them and they're hardly likely to care, given the quality is good and the price is affordable.

IV. Bands for IMT-2000 and IMT-Advanced

The requirements of IMT-Advanced include average downlink rates of 100 Mbit/s in the wide area network, and up to 1 Gbit/s for local access or low mobility scenarios. Therefore, IMT-Advanced calls for very wide channel widths. The technology needs 40 MHz and preferably up to 100 MHz channel allocations, according to Erik Ekudden,

vice president and head of standardization and industry initiatives at Ericsson. Never before have such large spectrum allocations been needed. And that means spectrum availability will be a big challenge for IMT-Advanced technologies. "It's up to governments and regulators around the world to allocate this spectrum." says Ekudden.

ITU WARC-92 (World Administrative Radio Conference of 1992) identified the initial 1885-2025 MHz and 2110-2200 MHz bands for IMT-2000 deployment, also called the core bands. WRC-2000 (World Radio Conference of 2000) identified three additional bands for terrestrial IMT-2000 i.e. 2500-2690 MHz, 806-960 MHz (in ITU Region 1 band 862-960 MHz) and 1710-1885 MHz.

WRC-07 (World Radio Conference of 2007) had deliberated for a month over Agenda item 1.4, which examined whether IMT status should be assigned to the following radio frequency bands, the so-called 'candidate bands': 410-430MHz, 450-470MHz, 470-862MHz, 2.3-2.4GHz, 2.7-2.9GHz, 3.4-3.6GHz, 3.6-3.8GHz, 3.8-4.2GHz and 4.4-4.99GHz. After what was described by the ITU as "intense negotiations", the ITU stated that "globally harmonized spectrum identified for use by IMT" would be the following: 450-470MHz, 698-806MHz in Region 2 (Americas) and nine countries of Region 3 (Asia/Oceania), 790-862MHz band in Regions 1 (Europe, MEA, Russia) and 3 (Asia/Oceania) 2.3-2.4GHz, 3.4-3.6GHz (no global allocation, but accepted by many countries). These frequencies are to be used by IMT technologies such as 3G cellular technologies and WiMAX, the newest member of the IMT family (recognized as IMT-2000 technology at WRC-07).

Together with previous band allocation to IMT-2000, IMT bands are 450-470 MHz, 698-960 MHz (790-960 MHz in Regions 1 and 3), 1710-2025 MHz, 2110-2200 MHz, 2300-2400 MHz, 2500-2690 MHz, 3400-3600 MHz.

The prime band for future mobile systems is considered to be the band 2500-2690 MHz.

On 13 June 2008 European Commission adopted a decision on the harmonisation of the 2500-2690 MHz frequency band for terrestrial systems capable of providing electronic communications services in the Community. With Member States planning to issue licenses starting in 2008, this decision ensures coherent technical conditions within the Community for the provision of services such as mobile Internet access.

Previously, on 21 May 2008 European Commission announced decision on the harmonisation of the 3400-3800 MHz frequency band for the same purpose.

A. GSM900 Spectrum Refarming

With reference to a possible re-use of 900 and 1800 MHz bands for the 3G technology ("refarming"), operators' interests seem to converge on 900 MHz frequencies. The 900 MHz band re-use is considered to be favourable due to the wider territory coverage for 3G mobile networks, compared to that reachable in 1800 and 2100 MHz bands (especially useful in rural areas, to reduce the number of base stations and decrease the costs) and higher penetration into the buildings (urban zones).

Europe's regulators have just begun to tackle these issues. In July 2007 the European Commission adopted a new policy allowing 900MHz refarming. The implementation is now up to individual member states. French regulator ARCEP has given OK to Orange and SFR to deploy 3G services using 900 MHz band frequencies previously reserved for GSM services. The move will enable the two companies to up their national 3G coverage to include virtually the entire French population. This move is in contrast to the stance being taken by Ofcom, the UK telecom regulator. Ofcom has asked Vodafone and Telefonica's O2 to give up part of the 2G spectrum they use in the 900 MHz, so that it can be auctioned to other telcos.

900MHz refarming is also allowed in Finland. Finnish service provider Elisa said it had become the first telco to offer 3G mobile services commercially in the 900 MHz radio frequencies and said the move would help reduce network costs by up to one third.

Spectrum refarming poses challenges for operators and regulators in several ways:

- Existing GSM 900 MHz infrastructure can introduce interference into UMTS 900 MHz networks, so guard band and transitional zones may be needed.
- Operators may need to carefully manage voice and data traffic loads between the 900 MHz and 2100 MHz bands
- Not all operators have 900 MHz spectrum, therefore refarming of GSM spectrum bands that are coming to the end of their license terms is needed to ensure that they are allocated to everyone fairly.

B. The "Digital Dividend" Spectrum

Digital Terrestrial Television (DTT) will replace analogue terrestrial television in the long term. In a communication published in May 2005, the EC strongly advocated that by 2012 all analogue terrestrial TV transmitters in Europe should be switched off in order to free up radio frequencies. Switch off of analogue terrestrial TV has already taken place in Luxemburg, the Netherlands, Finland and Sweden and in several areas in Germany.

The "digital dividend" spectrum i.e. the spectrum that will be released after the switchover to DTT, is valuable because it has good signal propagation for better coverage and getting inside buildings. Ideally for LTE, operators in Europe will want a blend of 2.6 GHz spectrum (which has only been auctioned in Norway and Sweden so far) in urban areas for high capacity and the digital dividend spectrum for coverage in rural areas.

On 24 September 2008 the European Parliament (EP) adopted a Resolution regarding European Commission (EC) Communication of 13 November 2007 on "reaping the full benefits of the digital dividend in Europe: a common approach to the use of the spectrum released by the digital switchover".

In the Resolution, the Parliament supports a common and balanced approach to the use of the digital dividend, which should "serve the general interest by ensuring the best social, cultural and economic value in terms of an enhanced and geographically wider offer of services and

digital content to citizens".

The European Parliament therefore urges Member States to release their digital dividends as quickly as possible, calling on them to develop national digital dividend strategies by the end of 2009 while following a common methodology.

In France it was announced that 72MHz of the "digital dividend" spectrum (790-862 MHz) is being allocated to electronic communications services to allow citizens to benefit from the deployment of new, innovative, and competitive services and to reduce the "digital divide".

The Swedish and Finnish governments have already decided to make the 790MHz - 862 MHz band available for mobile applications.

V. Flexible Spectrum Management

On 24 September 2008, the European Parliament adopted a resolution that amends Directives on Electronic Communications 2002/21/EC, 2002/20/EC and 2002/19/EC of 2002. Relevant to spectrum management are the following amendments (quote):

- The Body of European Regulators in Telecom (BERT) should be established to accomplish co-ordination between NRAs of Members States without harmonising existing regulatory approaches to a degree which undermines regulatory competition.
- Although spectrum management remains the competence of the Member States, only coordination and, where appropriate, harmonisation at Community level can ensure that spectrum users derive the full benefits of the internal market and that EU interests can be effectively defended world-wide.
- The provisions of this Directive relating to spectrum management should be consistent with the work of international and regional organisations dealing with radio spectrum management, such as the International Telecommunications Union (ITU) and the European Conference of Postal and Telecommunications Administrations (CEPT), so as to ensure the efficient management and harmonisation of the use of spectrum across the Community and globally.
- Radio frequencies should be managed so as to ensure that harmful interference is avoided. The basic concept of harmful interference should therefore be properly defined by reference to existing internationally agreed frequency plans to ensure that regulatory intervention is limited to the extent necessary to prevent such interference.
- Flexibility in spectrum management and access to spectrum should be increased through technology- and service-neutral authorisations to let spectrum users choose the best technologies and services to apply in frequency bands available for electronic communications services as identified in national frequency allocation plans and the ITU Radio Regulations (the "principles of technology and service neutrality"). The administrative determination of technologies and services should apply whenever general interest objectives are at stake.

More flexibility is also needed with regard licensing. For this the EC is proposing the possibility for Member States to trade and lease spectrum both at national and EU-level. This would make the redistribution of spectrum more dynamic, as well as be an incentive for the releasing of un- or under-used spectrum. While the EC believes that spectrum trading will promote competition, it nevertheless acknowledges the fact that it may also create competition challenges. Spectrum trading is permitted in the EU by Article 9 of the Directive 2002/21/EC. It requires:

- that transfers are notified to the national regulatory authority;
- that such transfers are carried out in accordance with procedures laid down by the national regulatory authority;
- that such transfers are made public, and
- that competition is not distorted as a result of any transfer

The European Commission announced its Radio Spectrum Committee decision to allow both TDD and FDD on the 2.6 GHz (2500-2690MHz) frequency band, which means that GSM and LTE cellular technologies using FDD will also be able to use the 2.3, 2.6 and 3.5 GHz frequencies, categorized by the WiMAX Forum as the key bands for Mobile WiMAX technology using TDD. This decision allows the European Union administrators to choose what technology, services and usage are to be deployed within the band. Thus, the market will be able to determine the appropriate usage of the spectrum and to create significant opportunities that customers will benefit from.

VI. A View from Republic of Macedonia

Republic of Macedonia is strongly engaged in the development of information society. The aim is to increase competitiveness and productivity, social and regional equality, as well as citizens' well-being and quality of life by means of information and communications technologies throughout society. Telecommunication infrastructure is an essential foundation for the information society. Therefore the "National Strategy for the Development of Electronic Communications with Information Technologies" was released in 2007 ([10]).

In the Republic of Macedonia currently there exist three mobile operators offering services in the GSM 900 MHz band: T-Mobile, Cosmofon and VIP Operator, a member of Mobilkom Austria Group. The band GSM1800 (DCS1800) is currently un-used.

The national regulator authority, the Agency for Electronic Communications (AEC), awarded a 3G licence in the UMTS 2100 MHz band to Cosmofon following a tender in November 2007 . Cosmofon is already offering 3G-HSDPA service at 3.6 Mbit/s.

At present, there is a tender opened for awarding 3 more licenses in the UMTS 2100 MHz band (ending November 13th 2008). The goal is to increase competition and drive prices of 3G services down.

There were two proposals for the introduction of BWA/WiMAX in the Republic of Macedonia. In July 2006, the Working group formed by the AEC and chaired by the author of this paper published the "Guidelines for introducing Fixed Wireless Access in the frequency band

3400-3600 MHz in the Republic of Macedonia" ([11]). This document called for: 3 national licenses, based on 2x21 MHz paired spectrum per operator, and a single 2x14 MHz paired spectrum for regional licensing. The initial license fee was set to half of the amount calculated based on the average European fee of $0.006 per 1 Hz and 1 million inhabitants from the report "Spectrum analysis - The Critical Factor in BWA/WiMAX versus 3G", by Maravedis Telecom Market Research & Analysis, from January 2006. This resulted in 200,000 EUR ($\$0.006 \times 42 \times 2,000,000 = \$500,000 = 400,000$ EUR, for population of two million).

The other proposal came from MASIT (Macedonian Information and Communication Technologies Chamber of Commerce). This proposal called for five 2x14 MHz paired spectrum blocks for regional licensing in five regions. No initial fee, and annual spectrum utilization fee in the range of 15,000 EUR per operator was proposed.

The final decision was to award 2 national licenses in two 2x14 MHz paired spectrum blocks and regional licenses in the rest of this band (three 2x14 paired spectrum blocks in each region). For regional licensing the whole territory of the Republic of Macedonia was divided into 6 regions with population between 222,000 and 578,000. The minimal initial fee was set to 100,000 EUR for national license, 50,000 EUR for Region 1 which includes the capital Skopje, and significantly lower amounts of 15,000 EUR and 10,000 EUR for the other regions.

As a result of the announced tender, 2 national licences were awarded. Two other operators got licenses for all 6 regions, and, thus, became operators with national coverage as well. One operator acquired licenses for operation in four regions and two other operators in a single region.

Most of the WiMAX operators are currently building their networks, and some of them have already started offering services. A request by the two operators with national coverage and adjacent frequency blocks was filed for swapping half of their paired spectrum which would provide them a contiguous block of twice as large unpaired spectrum in order to use TDD equipment (WiMAX 802.16e). AEC approved of this spectrum swapping. Allowing spectrum swapping was already recommended in [11] by the author of this paper, who strongly favors TDD over FDD. TDD has several advantages over FDD. One of them is the possibility to use assymetric download/upload rates. Another advantage is the fact that due to reciprocity, channel knowledge in the receive direction can be used for transmission (in TDD reception and transmission are in the same frequency band) facilitating the use of modern transmission technologies such as adaptive modulation, MIMO (Multiple Input Multiple Output) and beamforming ([12]).

Swapping spectrum is an example of introducing a more flexible spectrum allocation in Republic of Macedonia. The spectrum swap was approved in the best interest of both operators and customers. Employing TDD duplexing method will provide more efficient spectrum use. Still, care should be taken to avoid harmful interference to other FDD systems, such that requirements on transmission power (Maximum EIRP) and on out of band emissions (Block Edge Mask - BEM) should be met.

Currently, in Republic of Macedonia a National Broadband Internet Strategy is in preparation. An open public debate involving all the interested parties to set the framework of the strategy took place on October 31st 2008. Regarding spectrum management, there were suggestions to replace tenders, that are currently used for awarding licenses, with auctions, and consider introducing spectrum trading in the Republic of Macedonia. The author of this paper also called for more flexible spectrum management, i.e. to allow trading, liberalization, refarming.

Regarding spectrum use for mobile broadband in the Republic of Macedonia, the author of this paper gave the following propositions:

- Bands below 1 GHz to be used for coverage (rural areas)
  - use of the digital dividend spectrum 790-862 MHz
  - spectrum refarming of GSM900 band
  - explore the possibility to free up the band 450-470 MHz, currently used for other purposes
- Bands above 1 GHz to be used for capacity (urban areas)
  - consider the use of GSM1800 (DCS1800) band, which is currently unused
  - explore the possibility to free up the band 2300-2400 MHz, currently used for other purposes
  - postpone the assignment of band 2500-2690 until the next generation mobile broadband systems are available and/or new systems within IMT-Advanced are defined. Then, it would be possible to determine most appropriate block sizes for paired/unpaired spectrum licensing depending on the requirements of the future systems.

All the bands designated by ITU for IMT services should be used for these services. Notice that due to the fact that WiMAX is included in IMT, all these bands are available to WiMAX and its evolutions as well.

Bands under 1 GHz provide excellent propagation characteristics, and wide coverage of the whole territory at a reduced cost. Therefore, licensing these "precious" bands should be conditioned upon the obligation to provide coverage of the entire territory of the Republic of Macedonia, including the rural and sparsely populated areas. This could be a solution to bridge the existing"digital divide", and meet the EU goal to provide broadband internet to all its citizens by 2010.

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