4G: WHERE ARE WE GOING?

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Key words: Mobile communication, broadband communication, communication standards, radio spectrum management, communication system planning.

Abstract: While deployment of 3G broadband cellular mobile systems still leaves ample room for growth and upgrades, recently developed international standards and new spectrum allocation changes, as well as new systems development, stimulate early 4G deployment. The possible impact of these new developments is exemplified and quantified in terms of 4G aggregate throughput to be shared between individual users. The available data indicate that the user experience with the exemplified candidate 4G systems can be expected to be within the range of current wireline ADSL and cable modem broadband services. 2G/3G deployment indicators are presented that apparently have a bearing on the prevailing evolutionary 3G/4G trends among the leading incumbent mobile service providers aiming at 4G deployment to start in 2010, and attention is drawn to announced plans by other mobile service providers planning to start commercial 4G services in 2008 and 2009, respectively. Three possible scenarios for future 4G convergence and competition are submitted and discussed.

4G: Kam gremo?

Kjučne besede: mobilne komunikacije, širokopasovne komunikacije, komunikacijski standardi, upravljanje z radijskim spektrom, načrtovanje komunikacijskih sistemov

Izvleček: Čeprav uporaba širokopasovnih 3G celičnih mobilnih sistemov še vedno omogoča rast in izboljšave, pred kratkim sprejeti mednarodni standardi in spremembe v dodelitvi frekvenc, kot tudi razvoj novih sistemov, vzpodbujajo zgodnjo uvedbo sistemov 4G. Možen vpliv tega napredka ponazarja in kvantificira skupna prepustnost sistemov 4G, ki si jo med seboj naj delijo posamezni uporabniki. Dostopni podatki kažejo, da bi izkušnje uporabnikov s predlaganimi sistemi 4G, ki so navedeni kot primer, lahko bile primerljive s storitvami obstoječih žičnih ADSL in širokopasovnih kabelskih modemskih sistemov. Predstavljene izkušnje z uvajanjem sistemov 2G/3G imajo očitno zelo močan vpliv na razvojne usmeritve sistemov 3G/4G vodilnih obstoječih ponudnikov mobilnih storitev, ki nameravajo začeti z uvajanjem sistemov 4G v letu 2010. Obravnavani so tudi napovedani načrti drugih ponudnikov mobilnih storitev, ki načrtujejo komercialno uvedbo storitev 4G v letu 2008 ali v letu 2009. Opisani in obravnavani so trije možni scenariji bodoče 4G konvergence in konkurence.

Preface

My selection of the subject of this article is based on wishful thinking about still being able to chat with Lojze over the telephone or visiting him in his home. I imagine he could have said: "I read the August 2008 Focused Issue of the IEEE Microwave Magazine that you edited. Timely subject; would also be of interest to the readers of our Journal "Informacije MIDEM". Could you condense the information into a single article and include your comments?" This is what I decided to do.

1. Introduction

A straightforward single answer to the question in the title is elusive due to the complex interplay of a number of technological, regulatory and business issues. To develop an understanding of where we are really going, it is indispensable to direct attention to the activities of the International Telecommunication Union (ITU), the world's supreme standardization and regulatory body for telecommunications, in which the leading regional and national standardization development organizations (SDOs) and regulatory agencies systematically cooperate. ITU's Radiocommunication Sector (ITU-R) is therefore the most authoritative source of relevant information needed to evaluate the progress of cellular mobile communications.

Presenting key relevant information on this subject in a convenient format for use by the membership of the IEEE Microwave Theory and Techniques Society (MTT-S) was the intent of the August 2008 Focused Issue of the IEEE Microwave Magazine, one of the periodicals published by MTT-S. The focus was on convergence and competition on the way toward the 4^{th} generation of cellular mobile communication systems (4G), which are necessarily of great interest to a large segment of MTT-S membership, primarily those involved in or affected by the development of mobile communications. The author of this article served as guest editor /1/, and was fortunate to benefit from the participation of a prominent international group of authors engaged at the forefront of cellular mobile systems development and standardization /2-5/.

The following sections highlight the fundamental issues of convergence and competition on the way toward 4G, based primarily on the referenced articles /1-5/ that provide extensive reference lists for use by readers interested in more detail. Section 2 highlights the framework for 3G and 4G standards evolution, Section 3 summarizes frequency spectrum availability, Section 4 focuses on the effective spectral efficiency and throughput as key performance metrics, Section 5 highlights the 2G/3G deployment indicators and 4G trends, and Section 6 offers conclusions and comments.

2. Standards development

ITU-R standards development for cellular mobile systems started in 1985 and underwent a number of organizational changes /4/. The current framework consists of "International Mobile Telecommunications-2000" (IMT-2000) and "IMT-Advanced"; the term "IMT" was adopted for both collectively /6/. Two standards deserve particular attention: Recommendation ITU-R M.1457 on specifications of the IMT-2000 radio interfaces /7/, and Recommendation ITU-R M.1645 on objectives of the future development of IMT-2000 and systems beyond IMT-2000 /8/. Both refer to IMT-2000 as "third generation mobile systems". Recommendation ITU-R M.1457, originally adopted in 2000 and updated annually, introduced a family of five different 3G radio interfaces, including the two code division multiple access (CDMA) varieties currently deployed worldwide: wideband CDMA (WCDMA) and CDMA 2000. When Recommendation ITU-R M.1645, adopted in 2003, introduced a new category of mobile systems for more demanding future applications, tentatively named "Systems beyond IMT-2000", it was commonly considered to represent 4G, although this Recommendation does not refer to it as such. Figures 1 and 2 illustrate the concept of systems beyond IMT-2000 as described in Recommendation ITU-R M.1645.

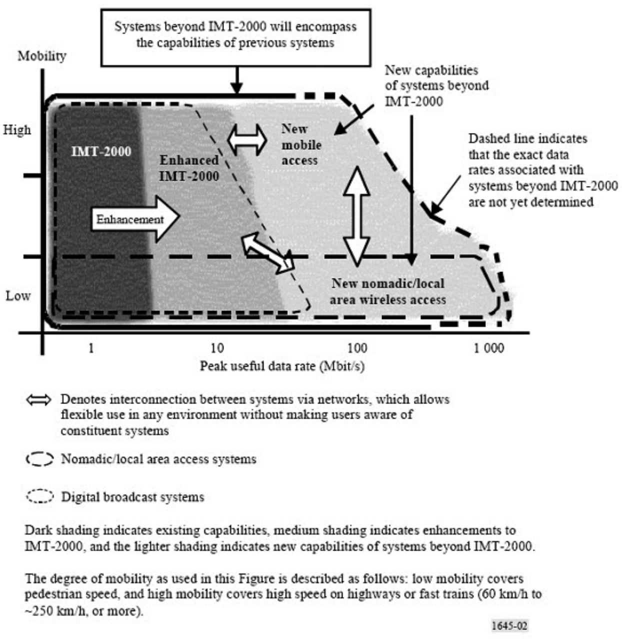

Fig. 1: Illustration of capabilities of IMT-2000 and systems beyond IMT-2000 /8/ (By authorization, ITU Legal Affairs.)

Generational identification was also avoided when "Systems beyond IMT-2000" was renamed "IMT-Advanced", and when Revision 7 of Recommendation ITU-R M.1457 was adopted, both in 2007. Notably, Revision 7 introduced orthogonal frequency division multiple access (OFDMA) radio interfaces. One of them is a new IMT-2000 member based on IEEE Std 802.16, supported by the WiMAX Forum, and the three additional ones represent 3G evolution, e.g. the long term evolution (LTE) and the ultra mobile broadband (UMB) versions that are broadband evolutions from WCDMA and CDMA2000, respectively /2-4/. Since an OFDMA radio interface is commonly considered as a key characteristic of 4G systems, Revision 7 of Recommendation ITU-R M.1457, which was initiated as a vehicle for 3G standardization, actually became a framework for transition to 4G. This unanticipated development seems to justify past avoidance of 4G identification in Recommendation ITU-R M.1645, and it makes it plausible at the current stage of Recommendation ITU-R M.1457 updating. Outside ITU-R, however, the generational terms are in widespread use, and WiMAX, LTE and UMB are commonly considered to represent 4G.

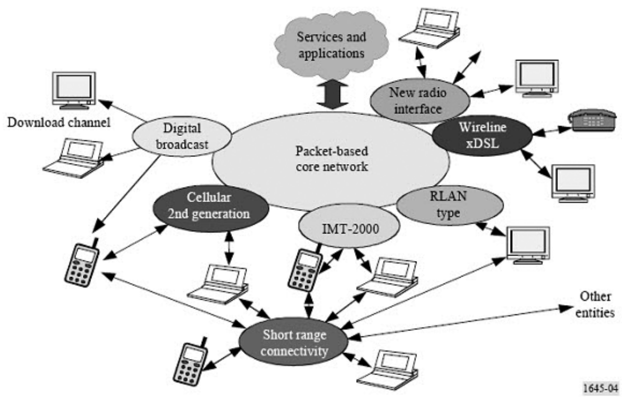

Fig. 2: Future network of systems beyond IMT-2000 including a variety of potential interworking access systems /8/ (By authorization, ITU Legal Affairs.)

The ITU-R framework for IMT-Advanced standardization was defined in 2007 /9/. The schedule calls for submitting proposals for candidate radio interface technologies (RITs) by October 2009, and for developing the necessary Recommendations and Reports by 2011. Foremost among the key features of IMT-Advanced are "target peak data rates of up to approximately 100 Mbit/s for high mobility such as mobile access and up to approximately 1 Gbit/s for low mobility such as nomadic/local wireless access" /8/. The relationship between peak data rates and throughput, which is indicative of expected user experience, is addressed in Section 5.

3. Frequency spectrum availability

Adequate frequency spectrum availability is a prerequisite for satisfactory mobile service provisioning. Growing market demand drives the expanding spectrum needs that are accommodated through appropriate revisions of the Table of Frequency Allocations in the ITU Radio Regulations. This is done at World Radio Conferences (WRCs) that take place every three to four years. In ITU-R terminology, frequency spectrum for IMT is "identified" within bands allocated to the mobile service. After the additions approved at WRC-

07, the frequency spectrum availability for IMT is as follows /1, 5/:

450-470 MHz

698-960 MHz

1 710-2 025 MHz

2 110-2 200 MHz

2 300-2 400 MHz

2 500-2 690 MHz

3 400-3 600 MHz

The current total of 1 077 MHz appears insufficient in view of the consensus estimates of IMT spectrum needs for the year 2010, which range from 1 280 MHz for low demand to 1 720 MHz for high demand, respectively /5/.

The bands 806-960 MHz, 1710-2025 MHz and 2110-2200 MHz are in current use for 2G and 3G services. The bands 450-470 MHz, 698-862 MHz, 2 300-2 400 MHz, and 3 400-3 600 MHz were additionally identified for IMT at WRC-07. There was also a proposal for adding the bands 3600-4200 MHz and 4400-4900 MHz for estimated additional future IMT needs, but it was not adopted due to objections from current users of these bands, foremost the fixed satellite service. No WRC follow up is scheduled at this time; the matter is neither on the WRC-11 agenda, nor on the WRC-15 preliminary agenda. Importantly, a number of regulatory restrictions on spectrum usage apply to specific bands in different regions and countries. The necessary follow-up regulatory proceedings for the newly identified bands for IMT, such as spectrum auctions and radio-frequency channel arrangements, are in progress at various stages in the different regions and countries. Since frequency spectrum is a limited natural resource, spectral efficiency is of particular significance.

Of special interest is the spectrum "refarming" undertaken in Japan to make the bands 3 600-4 200 MHz and 4 400-4 900 MHz available for IMT applications starting in 2012 /5/. This national initiative may stimulate international identification of one or both of these bands for IMT at a future WRC. The beneficial result would be to align spectrum availability closer with the estimated spectrum needs quoted above.

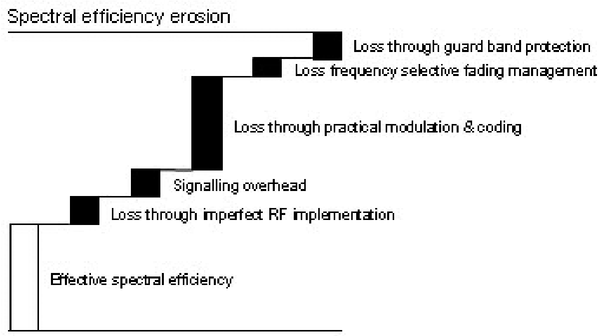

Fig. 3: Illustration of representative spectral efficiency erosion on an approximate dB scale. (Courtesy of Vodafone R&D.)

4. Effective spectral efficiency and throughput

The nominal spectral efficiency, which is the ratio of the peak system data rate to the channel bandwidth, is most commonly quoted. However, the more useful metric for system evaluation is the effective spectral efficiency, which accounts for system implementation losses /2/. Figure 3 illustrates the "erosion" from the nominal to the effective spectral efficiency.

The quantitative erosion of spectral efficiency determines the aggregate per carrier-sector throughput, which is available for sharing by simultaneous cell users. The most informative comparison of representative 3G and 4G systems presented in Table 1 of /3/ reveals the important fact that the effective spectral efficiencies for 4G systems are about double in comparison with 3G systems. Table 1 below, which is an excerpt from the referenced table /3/, compares the current candidate 4G systems, both frequency-division duplex (FDD) and time-division duplex (TDD).

Table 1: 4G comparison (excerpt from Table 1 in /3/). Based on 64 QAM in the downlink (DL), 16 QAM in the uplink (UL), spectrum reuse 1, and signalling overheads included /3/.

		OFDMA + 2x2 MIMO (4G)				
		WiMAX		**UMB**	**LTE**	
TDD (2:1)/FDD		**TDD (10 MHz)**	**FDD (5+5 MHz)**	**FDD (5+5 MHz)**	**TDD (10 MHz)**	**FDD (5+5 MHz)**
Peak data rate (Mbit/s)	DL	37.44	28.63	37.25	47.48	37.5
	UL	5.04	7.56	19.5	9.33	12.5
Aggregate throughput per carrier-sector (Mbit/s)	DL	7.88	5.25	8.1	11.93	7.95
	UL	2.55	3.83	4.0	2.5	3.75
Spectral efficiency (bits/s/Hz/carrier-sector)	DL	1.28		1.62	1.59	
	UL	0.72		0.8	0.79	

The aggregate throughput figures in Table 1 suggest that the user experience with the exemplified candidate 4G systems can be expected to be within the range of current wireline ADSL and cable modem broadband services. The achievable throughput for any individual mobile user depends on a number of parameters, such as specific system characteristics, propagation and interference conditions, traffic patterns, and the number of simultaneous cell users /8/.

5. 2G/3G deployment indicators and 4G trends

The most significant single statistical indicator is that global mobile penetration in terms of subscriptions recently surpassed 50%, which is an impressive achievement in spite of multiple subscriptions that are not accounted for /10/. About 99% of the world's mobile subscribers are served by two 2G/3G system families: GSM/WCDMA and cdmaOne/CDMA2000, respectively /1-3/. Their relative market shares are thus important statistical indicators. The last period for which directly comparable worldwide statistics for both 2G/3G families are available in the public domain as of this writing is the end of the first quarter of 2008 /11-12/. Their combined total number of subscribers amounted to about 3.5 billion. By comparison, the current number of fixed telephone lines totals about 1.3 billion. It is informative to differentiate the total mobile subscriptions in two ways, by system families, and by system generation. The approximate results are:

- market shares by system families were 87% for GSM/WCDMA vs. 13% for cdmaOne/CDMA2000;
- market shares by system generation were 81% for 2G vs. 19% for 3G.

Of particular interest are the market shares of the currently deployed advanced broadband versions of the two system families, high speed packet access (HSPA) and evolution-data optimized (1xEV-DO): 3.7% combined for end Q1 2008; 0.9% for HSPA and 2.8% for 1xEV-DO. Their modest broadband capabilities, e.g. aggregate per sector downlink throughputs of 0.95 Mbit/s in a 1.25 MHz band, and 2.6 Mbit/s in a 5 MHz band, respectively (Table 1 in /3/), indicate that 3G broadband deployment is still in its beginnings. HSPA and 1xEV-DO upgrades in progress are intended to substantially enhance 3G capabilities and improve cost effectiveness.

The above 2G/3G statistical indicators have apparently a bearing on prevailing 4G trends among the leading incumbent mobile service providers. The predominant ones that currently use the GSM/WCDMA system family naturally decided in favor of their own candidate, LTE, and are co-operatively supporting its standardization and development, aiming at commercial LTE launch in 2010 /13/. This includes even Verizon that currently uses the cdmaOne/CDMA 2000 system family /14/. However, another major incumbent service provider currently using the cdmaOne/CDMA 2000 system family, Sprint, is already deploying the commercially available WiMAX, and plans to start offering service in late 2008 /15/. And there are new competitive service entrants that decided to exploit the current time to market advantage of WiMAX, e.g. QU Communications in Japan, with plans to start commercial service in 2009 /16/.

What next for 4G? One possible scenario is a replay of 2G/3G history when cdmaOne was the trailblazer, evolved into CDMA 2000, and was the catalyst for WCDMA, but captured only a minor 2G/3G market share. In the replay, WiMAX is the trailblazer, and apparently the catalyst for LTE, but may likewise end up with a minor 4G market share as a consequence of the existing GSM/WCDMA dominance of the 2G/3G markets. Nevertheless, even a minor 4G market share is attractive. Another possible scenario is WiMAX-LTE convergence that is within reach due to their commonalities. This possibility was already publicly recognized both among service providers and system suppliers, e.g. /17, 18/. The IMT-Advanced framework /9/ offers an opportunity for implementing convergence but, at least as of this writing (September 2008), the IEEE 802.16m and LTE Advanced proposals for IMT-Advanced radio interfaces seem to progress in competition with each other and without apparent attempts toward convergence /4, 19/. Still another possible scenario is the use of a new OFDM radio interface variant, such as the one applying variable spreading factor (VSF) control to OFDM (VSF-Spread OFDM), which experimentally demonstrated 1 Gbit/s peak downlink data rate in a 100 MHz channel using 4x4 MIMO at speeds of up to about 30 km/hr /5/.

6. Conclusions and comments

Synergy between technological progress and service development stimulates convergence through standards development, on the one hand, and competition among both systems suppliers and service providers, on the other. While 3G deployment progressed slower than anticipated and still leaves ample opportunity for broadband upgrading, OFDMA technology push enables leapfrogging to all-IP 4G that offers substantially improved broadband capabilities, spectral efficiencies and cost effectiveness. This increases the service providers' options in satisfying the growing market pull for mobile broadband access with capabilities comparable to those of fixed networks.

The IMT-Advanced peak data rate objective of 100 Mbit/s for mobile applications is within reach of emerging 4G systems. However, their aggregate per carrier-sector throughputs available for sharing between simultaneous users are substantially lower due to system implementation losses. This means that 4G mobile broadband user experience can be expected to be comparable to current ADSL and cable modem broadband services. The IMT-Advanced objective of 1 Gbit/s peak data rate for nomadic applications promises aggregate throughputs that would assure user experience comparable to current fiber optic access, but pursuit of this objective seems less compelling because usage at such high data rates is more likely to occur in fixed locations. Nevertheless, mobile services are under unabated pressure to offer performance as close as possible to fixed networks, and this pressure is increasing with the growth of the mobile web /20/.

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