The History of WiMAX: A Complete Survey of the Evolution in Certification and Standardization for IEEE 802.16 and WiMAX

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***Abstract*—Most researchers are familiar with the technical features of WiMAX technology but the evolution that WiMAX went through, in terms of standardization and certification, is missing and unknown to most people. Knowledge of this historical process would however aid to understand how WiMAX has become the widespread technology that it is today. Furthermore, it would give insight in the steps to undertake for anyone aiming at introducing a new wireless technology on a worldwide scale. Therefore, this article presents a survey on all relevant activities that took place within three important organizations: the 802.16 Working Group of the IEEE (Institute of Electrical and Electronics Engineers) for technology development and standardization, the WiMAX Forum for product certification and the ITU (International Telecommunication Union) for international recognition. An elaborated and comprehensive overview of all those activities is given, which reveals the importance of the willingness to innovate and to continuously incorporate new ideas in the IEEE standardization process and the importance of the WiMAX Forum certification label granting process to ensure interoperability. We also emphasize the steps that were taken in cooperating with the ITU to improve the international esteem of the technology. Finally, a WiMAX trend analysis is made. We showed how industry interest has fluctuated over time and quantified the evolution in WiMAX product certification and deployments. It is shown that most interest went to the 2.5 GHz and 3.5 GHz frequencies, that most deployments are in geographic regions with a lot of developing countries and that the highest people coverage is achieved in Asia Pacific. This elaborated description of all standardization and certification activities, from the very start up to now, will make the reader comprehend how past and future steps are taken in the development process of new WiMAX features.**

***Index Terms*—WiMAX, Mobile WiMAX, Fixed WiMAX, IEEE 802.16, WiMAX Forum, ITU, IMT-2000, IMT-Advanced, certification, standardization.**

I. Introduction

MOST of IEEE 802.16 and WiMAX (Worldwide Interoperability for Microwave Access) related articles and surveys [1]–[6] focus on the latest technical specifications. As the number of pages per article is often limited, they can only briefly tackle the history, future trends and organizational aspects of IEEE 802.16 in the introduction of their main subject. The same holds for high level reports [7] which do neither give in-depth details about the ins and outs of the evolution of different task goups within relevant organizations, nor about the relationships between them.

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Some outstanding books [8]–[12] have been written about IEEE 802.16 but even there only an (extended) summary of the different standard revisions and amendments is listed while more fine-grained details about the standardization process within the different organizations were omitted.

Only [13] was found to be completely dedicated to the IEEE 802.16 standardization and WiMAX certification process, although much less elaborated. They tried to give a similar summary, but the role of the ITU was omitted, the earliest task groups and old nomenclature were not mentioned and no evolution in the set of certified devices was presented. A similar approach [14] was made for an IEEE project concerning Wireless Personal Area Networks, IEEE P802.15.

Within this survey article we therefore intend to give the reader a better understanding of the relations between the different organizations and institutions that are playing a major role in the development, commercialization and spreading of the IEEE 802.16 standards. We furthermore address some deprecated abbreviations that have occurred over time, e.g. IEEE P802.16.1, in order for the reader to recognize them in the future and to relate them with the current terminology. The common misuse or confusion with respect to some other terms, e.g. IEEE 802.16d *(sic)*[1], is also tackled. While processing the various meeting minutes, project requests, task group studies, liaison documents, etc., we want the reader to provide with all relevant official documents where key decisions were taken or confirmed during the IEEE 802.16 related evolution, resulting in an exhaustive reference list. For the reader's convenience, an overview of the acronyms that are used within this manuscript is given in Table I.

The global picture is the following. The *IEEE* has specified a series of IEEE 802.16 standards, for the purpose of fixed and mobile broadband wireless access. The development process of those standards is described in Section II. Based on the IEEE 802.16 standards, the *WiMAX Forum* created the Fixed WiMAX and Mobile WiMAX profiles in order to guarantee interoperability between different products. The development of those profiles and the certification process of products that comply with those specifications is elaborated upon in Section III. Furthermore, the recognition of this technology by the *ITU* allowed spectrum owners to roll out WiMAX easier in different countries. The involvement of the IEEE in the ITU is explained in Section IV. Next we present a *trend analysis* of WiMAX technology over time, based on the IEEE

[1]*(sic)* is used in this article to indicate an erroneous expression

802.16 session attendance, the number of products which have been certified, the number of deployments, etc. in Section V. Finally, conclusions are drawn in Section VI.

II. The role of IEEE

Within this section, the evolution within the IEEE 802.16 Working Group on Broadband Wireless Access is discussed, as WiMAX technology is based on the standards that were developed therein. The umbrella organizations of this Working Group are first discussed in Section II-A, to acquaint the reader of its larger context. Next, the process of standardizing this work into international widespread IEEE Standards is elaborated in Section II-B. A detailed overview and time line of the precise projects and their resulting standards on the new air interface is then presented in Section II-C. Projects concerning topics other than the air interface are discussed next in Section II-D. Finally, a summary of the current (May 2011) IEEE 802.16 standards is given in Section II-E.

A. About the organization

IEEE (Institute of Electrical and Electronics Engineers) is an international well-known professional organization about engineering on areas including aerospace systems, computers, telecommunications, biomedical engineering, etc. It was founded on 1 Jan. 1963 by merging the former AIEE (American Institute of Electrical Engineers) and IRE (Institute of Radio Engineers). Today, it has over 375,000 members in more than 160 countries, half of whom are USA citizens. It has more than 2 million documents in the IEEE/IET Electronic Library and sponsors more than 900 conferences annually [15]. IEEE is organized into 38 societies (e.g. Communications Society, Computer Society, etc.) and 7 technical councils (which are groups of societies working together).

Within the IEEE Computer Society [16], the *IEEE-802 LAN/MAN Standards Committee (LMSC)* [17][2] is one of the multiple standards committees of the Standards Activity Board (SAB). The LMSC develops Local Area Network (LAN) and Metropolitan Area Network (MAN) standards [18], mainly for the lowest 2 layers of the ISO (International Organization for Standardization) Reference Model for Open Systems Interconnection (OSI) [19].

Within the LMSC, there are a number of Working Groups (WGs) and one Executive Committee (EC), which includes amongst others all WG chairs. One of the LMSC Working Groups is the *IEEE 802.16 Working Group on Broadband Wireless Access Standards*, which we will refer to as IEEE 802.16 WG in short. An overview of the relevant entities within the IEEE organization is shown in Fig. 1.

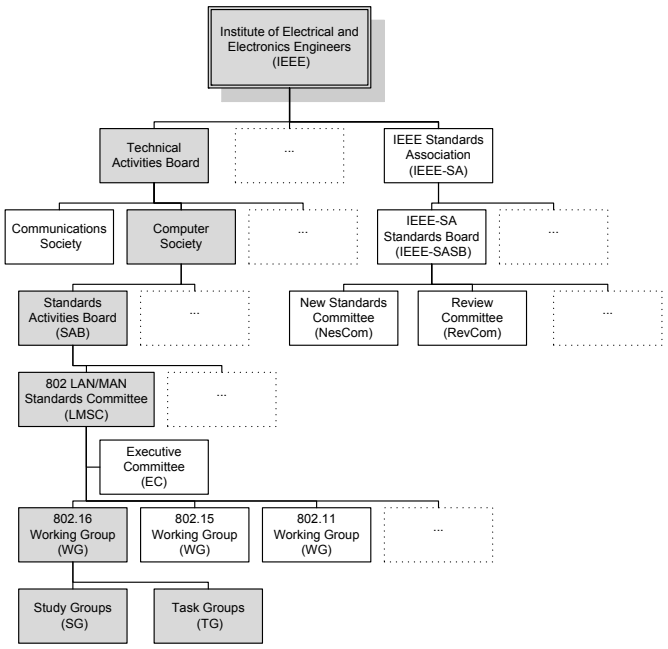

Fig. 1. Reduced hierarchical view on the IEEE organization, showing only the most relevant entities for the IEEE 802.16 WG.

B. The standardization process

Projects within Working Groups intend to result in standards that are published by the *IEEE-SA (IEEE Standards Association)*, which is an activity area of IEEE focused on the development of internationally recognized consensus standards through an open process, approved by the American National Standards Institute (ANSI). The standardization process is described below and an overview flow chart in shown in Fig. 2.

PARs (Project Authorization Request) are the means by which standards projects are started in the IEEE-SA. PARs are small but detailed documents that define the scope, purpose, and contact points for the new project. Every PAR must have a Sponsor to oversee the project, which is the organization that assumes responsibility for this particular standards idea within IEEE. The Sponsor may form a *Study Group (SG)* to write the PAR proposal [20]. PARs of the IEEE 802.16 WG are sponsored by the LMSC.[3]

In LMSC, new project proposals have also to fulfill some additional requirements. They have to provide supporting material in the form of *5-Criteria* (i.e. Broad Market Potential, Compatibility, Distinct Identity, Technical Feasibility, Economic Feasibility) to show that they meet the charter of LMSC [21]. The final PAR and 5-Criteria, developed by the SG, are reviewed by the IEEE 802.16 WG and the LMSC EC. If approved, the PAR is then submitted, normally within six months of the start of the work, by the LMSC to the *New Standards Committee (NesCom)* of the *IEEE-SA Standards Board (IEEE-SASB)* (see Fig. 1). The committee examines the PAR and makes recommendations to the IEEE-SASB regarding approval.

Once a PAR is approved by IEEE-SASB, the SG is disbanded [20] and a Sponsor will typically assign a working group or a (separate) *Sub-Group or Task Group (TG)* within the WG to prepare and develop successive draft documents that could eventually lead to the publication of the document as a new standard. Each project approved within an existing group is referred to by assigned suffix letter(s) together with

[2]The IEEE-802 LAN/MAN Standards Committee is referred to by different abbreviations: IEEE-802 LMSC, IEEE-802, LMSC, C/LM.

[3]Cosponsored by the Standards Coordinating Committee of the IEEE Microwave Theory and Techniques Society (MTT/SCC).

TABLE I
ACRONYMS WITHIN THIS ARTICLE.

Acronym	Definition	Acronym	Definition
3G	third generation	NWG	Network Working Group
3GPP	3rd Generation Partnership Project	OFDMA	Orthogonal Frequency Division Multiple Access
3GPP2	3rd Generation Partnership Project 2	OSI	Open Systems Interconnection
AIEE	American Institute of Electrical Engineers	PAR	Project Authorization Request
ANSI	American National Standards Institute	PCT	Protocol Conformance Testing
ARIB	Association of Radio Industries and Businesses	PG	Project Group
BCG	Band Class Certification Group	PHY	Physical
BWA	Broadband Wireless Access	PICS	Protocol Implementation Conformance Statement
CALA	Caribbean and Latin America Region	PIXIT	Protocol Implementation Extra Information for Testing
CDMA	Code Division Multiple Access	RA	Radiocommunication Assembly
CRSL	Certification Requirements Status List	RAG	Radiocommunication Advisory Group
CWG	Certification Working Group	RAN	Radio Access Network
DECT	Digital Enhanced Cordless Telecommunications	RCT	Radio Conformance Test
EC	Executive Committee (of LMSC)	RevCom	Review Committee of IEEE-SASB
EDGE	Enhanced Data rates for Global Evolution	RIT	Radio Interface Technology
EIA	Electronic Industries Alliance	RRT	Radio Regulatory Testing
ETSI	European Telecommunications Standards Institute	SAB	Standards Activity Board
EV-DO	Evolution-Data Optimized	SC	Single Carrier
FDD	Frequency Division Duplex	SCa	Single Carrier
FDMA	Frequency Division Multiple Access	SDD	System Description Document
FPLMTS	Future Public Land Mobile Telecommunications Systems	SG	Study Group
GCS	Global Core Specification	SGWG	Smart Grid Working Group
GRIDMAN	Greater Reliability In Disrupted Metropolitan Area Networks	SPWG	Service Provider Working Group
GRWG	Global Roaming Working Group	TDD	Time Division Duplex
HiperMAN	High Performance Metropolitan Area Networks	TDMA	Time Division Multiple Access
HSPA	High Speed Packet Access	TG	Task Group
IEEE	Institute of Electrical and Electronics Engineers)	TIA	Telecommunications Industry Association
IEEE-SA	IEEE Standards Association	TP	Test Purpose
IEEE-SASB	IEEE-SA Standards Board	TSC	Technical Steering Committee
IIOT	Infrastructure Inter-Operator Testing	TSS	Test Suite Structure
IMT-2000	International Mobile Telecommunications-2000	TTA	Telecommunications Technology Association
IRE	Institute of Radio Engineers	TWG	Technical Working Group
ISO	International Organization for Standardization	UMTS	Universal Mobile Telecommunications System
ITU	International Telecommunication Union	UTRA	Universal Terrestrial Radio Access
ITU-D	ITU Development	UWC	Universal Wireless Communication
ITU-R	ITU Radiocommunications	WARC	World Administrative Radio Conference
ITU-T	ITU Telecommunications	WCB	WiMAX Certification Body
LAN	Local Area Network	WCDMA	Wideband CDMA
LMDS	Local Multipoint Distribution Service	WCI	WiMAX 2 Collaboration Initiative
LMSC	LAN/MAN Standards Committee	WFDCL	WiMAX Forum Designated Certification Labs
LTE	Long Term Evolution	WFDVL	WiMAX Forum Designated Validation Laboratories
M2M	Machine to Machine	WG	Working Group
MAC	Medium Access Control	WiBro	Wireless Broadband
MAN	Metropolitan Area Network	WiMAX	Worldwide Interoperability for Microwave Access
MIOT	Mobile Interoperability Testing	WirelessHUMAN	Wireless High-Speed Unlicensed Metropolitan Area Network
MMR	Mobile Multi-hop Relay	WirelessMAN	Wireless Metropolitan Area Networks
NCT	Network Conformance Testing	WMAN	Wireless Metropolitan Area Network
NesCom	New Standards Committee of IEEE-SASB	WP	Working Party
NRR	Network Robustness and Reliability	WRC	World Radiocommunication Conference
N-WEST	National Wireless Electronic Systems Testbed		

a leading 'P' character (for Project) in its project number (e.g P802.16m) [22].

The final draft document will first undergo a *balloting process* amongst the WG members. Next, the draft document is forwarded to the Sponsor EC for approval and a Sponsor balloting process is initiated. To reach consensus (i.e. agreement among the majority, not necessarily unanimity) during the balloting processes, balloting group members are casting votes ("Approve", "Do Not Approve" or "Abstain"), with or without accompanying comments, in one or more successive ballots until completion of the standards balloting process. There are often multiple successive ballots as changes may be made in the proposed standard to resolve negative comments or for other reasons to improve the draft document. All substantive changes made since the last balloted proposed standard are identified and recirculated to the balloting group, together with all unresolved "Do Not Approve" votes with comments. During a *recirculation ballot*, balloting group members have an opportunity to cast votes or change their previously cast votes [23]. In order to proceed to the next

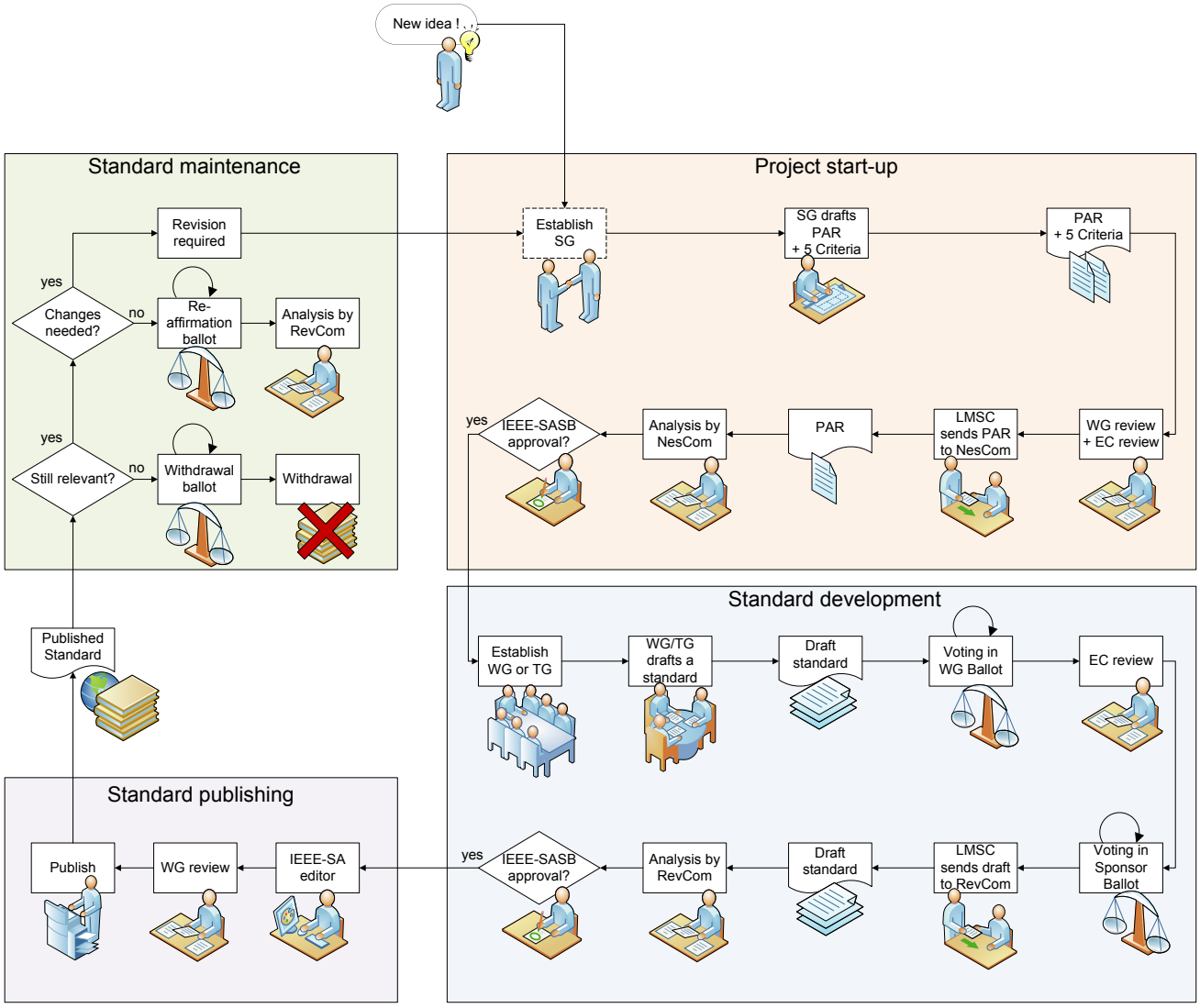

Fig. 2. Simplified flow chart of the IEEE standardization process for IEEE 802.16 standards and amendments.

stage, a minimum of 75% (excluding the "Abstain" votes) must approve the draft. In the event that 30% or more of the returned ballots are Abstentions, the standards balloting process shall be considered invalid.

After the Sponsor Ballot process is complete, the Sponsor will move the project toward final review by *RevCom (the Review Committee of IEEE-SASB)*, which issues a recommendation to the IEEE-SASB. The IEEE-SASB takes the final decision in approving the standard. After approval, the standard is edited by an IEEE-SA editor, given a final review by the members of the working group, and published. Additionally, IEEE 802 standards are added six months after publication to the IEEE Get 802 program for public download from the Internet, free of charge. At least every five years, every IEEE Standard is subjected to review for revision, reaffirmation or withdrawal [23].

If a standards project has not been completed by the four-year deadline authorized in the PAR and the Sponsor determines that the project should remain active, the Sponsor needs to complete the IEEE-SASB Extension Request Form and submit it to the NesCom. A PAR extension may be granted for one or more years [23].

C. IEEE 802.16 WG air interface standards

The IEEE 802.16 WG develops standards and recommended practices to support the development and deployment of broadband Wireless Metropolitan Area Networks (WirelessMAN). The Working Group has completed different standards projects since 2001 [24].

1. The original standard and first amendments

It all started with the establishment of the *IEEE 802 Study Group on Broadband Wireless Access (BWA)* [25] in Nov. 1998. This Study Group was also denoted as *802.N-WEST*, as the leader of this SG was Roger B. Marks who was at that time director of the National Wireless Electronic Systems Testbed (N-WEST) at the National Institute of Standards and Technology (NIST). The PAR [26] that was proposed by the SG for specification of interoperable Local Multipoint Distribution Service (LMDS) system was approved in Mar. 1999 and created the *P802.16* project. The SG was disbanded

and the *IEEE 802.16 Working Group on Broadband Wireless Access Standards* was erected to manage this newly approved project. Roger B. Marks is still leading this WG today.

In the P802.16 project, *Task Group 1 (TG1)* [27] focused on the development of an air interface for 10-66 GHz using a single carrier at the physical layer, which is therefore named WirelessMAN-SC (Single Carrier). However, in order to be consistent with the numbering of the concurrent project P802.16.2 (PAR [28] approved in Sep. 1999 under the auspices of Task Group 2 [29] for the development of a recommended practice for coexistence, see Section II-D3), it was requested in Nov. 1999 to renumber P802.16 as *P802.16.1* [30] (approved in Jan. 2000).

Also in Nov. 1999, the *Sub10 Study Group*[4] [31] was established for drafting an additional PAR to create a complementary standalone standard for an air interface for 2-11 GHz. This PAR was approved in Mar. 2000 as project *P802.16.3* [32][5] and *Task Group 3* [34] was established for its development (and Sub10 SG was disbanded). Within the project, three different options for the physical layer at 2-11 GHz were developed: WirelessMAN-SCa[6] (Single Carrier), WirelessMAN-OFDM (Orthogonal Frequency Division Multiplexing) and WirelessMAN-OFDMA (Orthogonal Frequency Division Multiple Access).

Then, in Dec. 2000 yet another PAR [35], this time drafted by the *WirelessHUMAN (Wireless High-Speed Unlicensed Metropolitan Area Network) Study Group* [36], was approved. This resulted in project *P802.16.1b* for the newly erected *Task Group 4 (TG4)* [37]. The project aimed at amending the standard (that would result from project P802.16.1) to support license-exempt frequencies, thereby defining a WirelessHUMAN physical air interface.

At the start of 2001, the 802.16 WG thus had three active projects concerning air interfaces: P802.16.1, P802.16.1b and P802.16.3[7]. However, the Working Group did not fully foresee those future projects. Due to the fact that it was agreed to continue the development of the different physical layer options but with only a single MAC protocol on top, the existing PARs were not fully aligned with the plans of the Working Group. Therefore, it was intended [38] to bring all of the air interface projects into a single standard, to be numbered simply '802.16'. Each additional air interface specification would be developed as an amendment[8]. This led in Mar. 2001 to the approval of the renumbering of P802.16.1 to *P802.16* [39] (which was actually its original project number [26] as explained earlier), the renumbering of P802.16.3 to *P802.16a* [40] and finally P802.16.1b to *P802.16b* [41]. The active PARs for air interfaces were now P802.16, P802.16a and P802.16b.

In May 2001, TG3 and TG4 agreed to work together [42], [43] in the same document for P802.16a and P802.16b. Because of this however, it was necessary in Nov. 2001 to redefine the PAR of P802.16a [44] to incorporate the goals of project P802.16b and to withdraw the latter, in order to comply with IEEE stipulations [45]. TG3 and TG4 were merged into *Task Group a (TGa)* [46] to manage development of the redefined P802.16a project.

On 6 Dec. 2001, the final draft document D5 of P802.16 within TG1 was approved [47] by IEEE-SASB. Finally a new IEEE standard was born: *IEEE Std 802.16-2001* [48]! It was published in Apr. 2002 [49].

Meanwhile, a new PAR [50] was submitted in Mar. 2002 for amending the standard with 'Detailed System Profiles for 10-66 GHz', which envisaged the definition of a number of profiles including a set of predetermined parameter values for interoperability support (more information on interoperability is found in Section III). This was approved in May 2002 [51] and led to *P802.16c*, managed by *Task Group c (TGc)* [52]. This project experienced a swift content output and its draft document D4 was already approved [53] by IEEE-SASB on 11 Dec. 2002 as *IEEE Std 802.16c-2002* [54]. It was the first amendment to IEEE Std 802.16-2001 and was published in Jan. 2003.

Also in Dec. 2002, a PAR [55] was approved for developing a draft for another amendment to IEEE Std 802.16-2001 in project *P802.16d*, similar in concept as P802.16c but now focusing on the lower frequencies, 2-11 GHz, for defining profiles for interoperability support. The work of *Task Group d (TGd)* [56] intended to result in 'Amendment 3: Detailed System Profiles for 2-11 GHz' but this never happened, as will be explained a little further.

About a month after the IEEE Std 802.16c-2002 approval, TGa also had its draft document D7 in P802.16a approved [57] on 29 Jan. 2003 by IEEE-SASB. This led to the IEEE standard *IEEE Std 802.16a-2003* [58], which was the second amendment to IEEE Std 802.16-2001 and published in Apr. 2003.

In 2003, to summarize, the following IEEE standards describing the air interface were thus applicable:

- IEEE Std 802.16-2001: IEEE Standard for Local and metropolitan area networks Part 16: Air Interface for Fixed Broadband Wireless Access Systems
  - IEEE Std 802.16c-2002: Amendment 1: Detailed System Profiles for 10-66 GHz
  - IEEE Std 802.16a-2003: Amendment 2: Medium Access Control Modifications and Additional Physical Layer Specifications for 2-11 GHz

Their evolution, as described above, is visualized in Fig. 3 and summarized in Table II.

2. Towards a first revision with new amendments

In the meantime, a *Mobile Wireless MAN Study Group* [59] was erected to draft a PAR concerning the addition of mobility, by making amongst others the number of subcarriers in WirelessMAN-OFDMA scalable with the used bandwidth. This PAR [60] was approved in Dec. 2002 leading to project *P802.16e*, tackled by *Task Group e (TGe)* [61].

After discussions in joint TGe/TGd meetings [62] during the WG meeting in May 2003, the scope of their current PARs appeared to be limiting their development. Therefore, it was

[4]The Sub10 SG originally aimed at frequencies below 10 GHz, however its scope was extended to the 2-11 GHz spectrum.

[5]While drafting the P802.16.3 PAR, it was briefly considered to create an amendment rather than a complementary standard. In this case the P802.16.1a number would have been applicable. This was however rejected [33].

[6]Note that the physical air interface using a single carrier is thus denoted 'WirelessMAN-SC' for 10-66 GHz and 'WirelessMAN-SCa' for 2-11 GHz.

[7]P802.16.2 was the fourth active PAR at the beginning of 2001 and dealt with coexistence issues, see Section II-D3

[8]Previous IEEE terminology for an 'amendment' was a 'supplement'

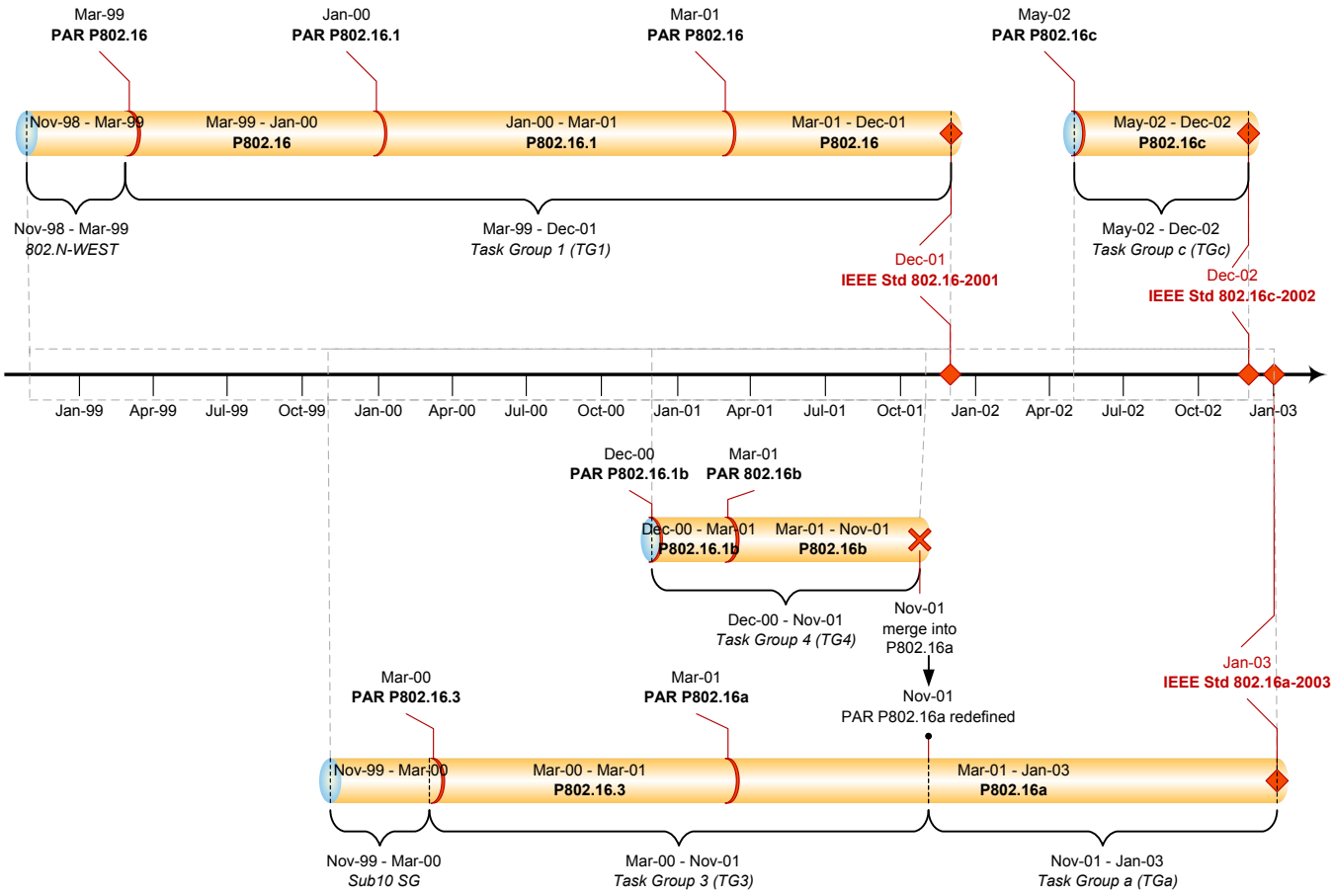

Fig. 3. Timeline with relevant PARs, SGs and TGs for IEEE Std 802.16-2001 and its amendments.

TABLE II
SUMMARY OF THE PROJECTS WITHIN THE IEEE 802.16 WG THAT LED TO IEEE STD 802.16-2001 AND ITS AMENDMENTS.

Project	P802.16 → P802.16.1 → P802.16	P802.16.3 → P802.16a	P802.16.1b → P802.16b	P802.16c
Study Group	802.N-WEST SG	Sub10 SG	WirelessHUMAN SG	-
PAR approval date	Mar. 99	Mar. 00	Dec. 00	Mar. 02
Task group	TG1	TG3 → TGa	TG4	TGc
Purpose	air interface for licensed bands in 10-66 GHz for LoS (WirelessMAN-SC)	adds air interfaces for licensed bands in 2-11 GHz for nLoS (WirelessMAN-SCa, WirelessMAN-OFDM, WirelessMAN-OFDMA)	adds license-exempt bands (WirelessHUMAN)	adds 10-66 GHz system profiles (for interoperability)
Project status	completed	completed	merged in P802.16a	completed
Final draft	D5	D7	-	D4
IEEE-SASB approval date	Dec. 01	Jan. 03	-	Dec. 02
Publishing date	Apr. 02	Apr. 03	-	Jan. 03
Standard	IEEE Std 802.16-2001	IEEE Std 802.16a-2003	-	IEEE Std 802.16c-2002
Standard status	obsoleted	obsoleted	-	obsoleted

decided to convert the P802.16d project into revision project *P802.16-REVd* for updating IEEE Std 802.16-2001 and its amendments into a single consolidated revision, rather than just amending it with system profiles for 2-11 GHz. In Sep. 2003, this new PAR [63] was approved. The work of TGd finally led on 24 Jun. 2004 [64] to the approval of draft D5 as *IEEE Std 802.16-2004* [65], obsoleting IEEE Standard 802.16-2001 and its two amendments (IEEE Std 802.16c-2002 and IEEE Std 802.16a-2003). It was published in Oct. 2004. Also in Jun. 2004, TGe requested to update its PAR to reflect the changes in this new revision. Approval was granted in Sep. 2004 [66].

Note that a final IEEE standard denoted as 'IEEE Std 802.16d *(sic)*' or 'IEEE Std 802.16d-2004 *(sic)*' thus never existed and neither is it a synonym for IEEE Std 802.16-2004. It is simply wrong to use this term.

A PAR for a corrigendum, to quickly correct errors that may still be found in IEEE Std 802.16-2004, was initiated and forwarded to NesCom in Jul. 2004 and approved as *P802.16-2004/Cor1* in Sep. 2004 [67]. This corrigendum was handled by a new *Maintenance Task Group* [68].

Earlier, in Mar. 2004, the WG created the new 802.16 *Network Management Study Group* [69]. The SG drafted two PARs, one to develop a Management Information Base for fixed service and another to develop Management Plane Procedures and Services to include both fixed and mobile service. Both were submitted in Jun. 2004 and approved in Aug. 2004. The former resulted in *P802.16f* [70], the latter in *P802.16g* [71]. The projects were both handled by a new TG: the *Network Management Task Group* [72].

Also in Mar. 2004, the WG erected an *Ad Hoc Committee on License-Exempt Coexistence* to provide the WG with recommendations regarding initiating standardization for license-exempt coexistence. The Committee proposed the creation of an IEEE 802.16 *Study Group on License-Exempt Coexistence* [73], which was established in Jul. 2004. The SG submitted a draft PAR [74] in Oct. 2004, approved in Dec. 2004, for the initiation of a new standardization project *P802.16h*, managed by a new TG: the *License-Exempt (LE) Task Group* [75]. Its work will allow sharing of a frequency channel between co-located operators by means of amongst others a Coexistence Frame (CX-Frame).

The draft document D6 in P802.16f of the Network Management Task Group was approved [76] as *IEEE Std 802.16f-2005* [77] in Sep. 2005 (and published in Dec. 2005). It was the first amendment to IEEE Std 802.16-2004. In the following month, Oct. 2005, the Network Management Task Group prepared a PAR to initiate a mobile management information base (and thus essentially extending the P802.16f work to support the new features of P802.16e). This was approved in Dec. 2005 as *P802.16i* [78].

Meanwhile, there was a lot of progress in P802.16e within TGe. Following its IEEE-SA approval on 7 Dec. 2005 [79], draft document D12 was published on 28 Feb. 2006 as *IEEE Std 802.16e-2005* [80], the second amendment to IEEE Std 802.16-2004. Prior to publication, the standard was fully integrated with the corrigendum *IEEE Std 802.16-2004/Cor1*, which was approved on 8 Nov. 2005 [81] and the result of draft document D5 within P802.16-2004/Cor1 of the Maintenance Task Group.

Note that a final IEEE standalone standard denoted as 'IEEE Std 802.16-2005 *(sic)*' thus never existed. It is incorrect to use this term. Only IEEE Std 802.16e-2005 can be used rightfully and compliance to IEEE Std 802.16e-2005 alone is impossible, since it's just an amendment to IEEE Std 802.16-2004 [82], [83].

In Jul. 2005, an *ad hoc committee on Mobile Multi-hop Relay* had led to the formation of a *Mobile Multi-hop Relay (MMR) Study Group* [84] within the 802.16 WG. This SG expired in Mar. 2006, with the approval of its PAR *P802.16j* [85]. The development of the P802.16j project had been assigned to the new IEEE 802.16's *Relay Task Group* [86], where adaptations are made to the physical WirelessMAN-OFDMA specifications, by including a transparent time zone for relay station (RS) to mobile station (MS) transmissions.

In Jul. 2006 the Maintenance TG drafted a new PAR *P802.16-2004/Cor2* [87] to open a Corrigendum 2 to IEEE Std 802.16-2004, which was approved in Sep. 2006.

The WG furthermore drafted a PAR [88] for a new *P802.16m*[9] project in Nov. 2006 for the development of an advanced IEEE 802.16 air interface, WirelessMAN-Advanced, suitable for consideration in the IMT-Advanced program being conducted by the International Telecommunications Union - Radiocommunications Sector (ITU-R) (see section IV). This was approved in Dec. 2006 and a new *Task Group m (TGm)* [89] was created for its development.

In Feb. 2007, the WG also forwarded PAR P802.16 [90] to develop a revision of IEEE Std 802.16, consolidating IEEE Std 802.16-2004 and its amendments, which was approved in Mar. 2007 and is managed by the Maintenance Task Group. Although the official name for this PAR, following IEEE-SA conventions, is *P802.16*, internally the unofficial name *P802.16Rev2* was used to differentiate from the very first P802.16 project. P802.16Rev2 indicates that the development within this project is about the second revision of IEEE Std 802.16. (The first revision was IEEE Std 802.16-2004, following the original version IEEE Std 802.16-2001) [91].

As a new revision was being drawn up for IEEE Std 802.16 in P802.16Rev2, one could as well directly incorporate the corrigendum that was being prepared at that time in P802.16-2004/Cor2. The WG therefore decided to request the withdrawal (effective in Sep. 2007) of the P802.16-2004/Cor2 PAR, and move the content of its last draft document, D4, into the P802.16Rev2 revision project [92].

Yet, while a new revision was being made, *IEEE Std 802.16g-2007* [93] was still approved [94] by the IEEE-SA Standards Board on 27 Sep. 2007 as the third amendment to IEEE Std 802.16-2004. It was the result of draft D9 in P802.16g of the Network Management TG and was published on 31 Dec. 2007.

To summarize, only the following IEEE standards describing the air interface were applicable in the beginning of 2008:

- IEEE Std 802.16-2004: IEEE Standard for Local and metropolitan area networks Part 16: Air Interface for Fixed Broadband Wireless Access Systems
  - IEEE Std 802.16f-2005: Amendment 1: Management Information Base
  - IEEE Std 802.16-2004/Cor1-2005: Corrigendum 1 (not published separately, but jointly with IEEE Std 802.16e-2005)
  - IEEE Std 802.16e-2005: Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands
  - IEEE Std 802.16g-2007: Amendment 3: Management Plane Procedures and Services

Their evolution, as described above, is visualized in Fig. 4 and summarized in Table III.

3. Completion of the second revision and the creation of new projects

[9] 'm' was the next available letter, because P802.16k had been approved meanwhile (see Section II-D1) and the IEEE-SA project numbering policy does not allow the letters 'l' nor 'o' for project numbers [22], probably because they resemble the numbers '1' and '0' which could cause confusion.

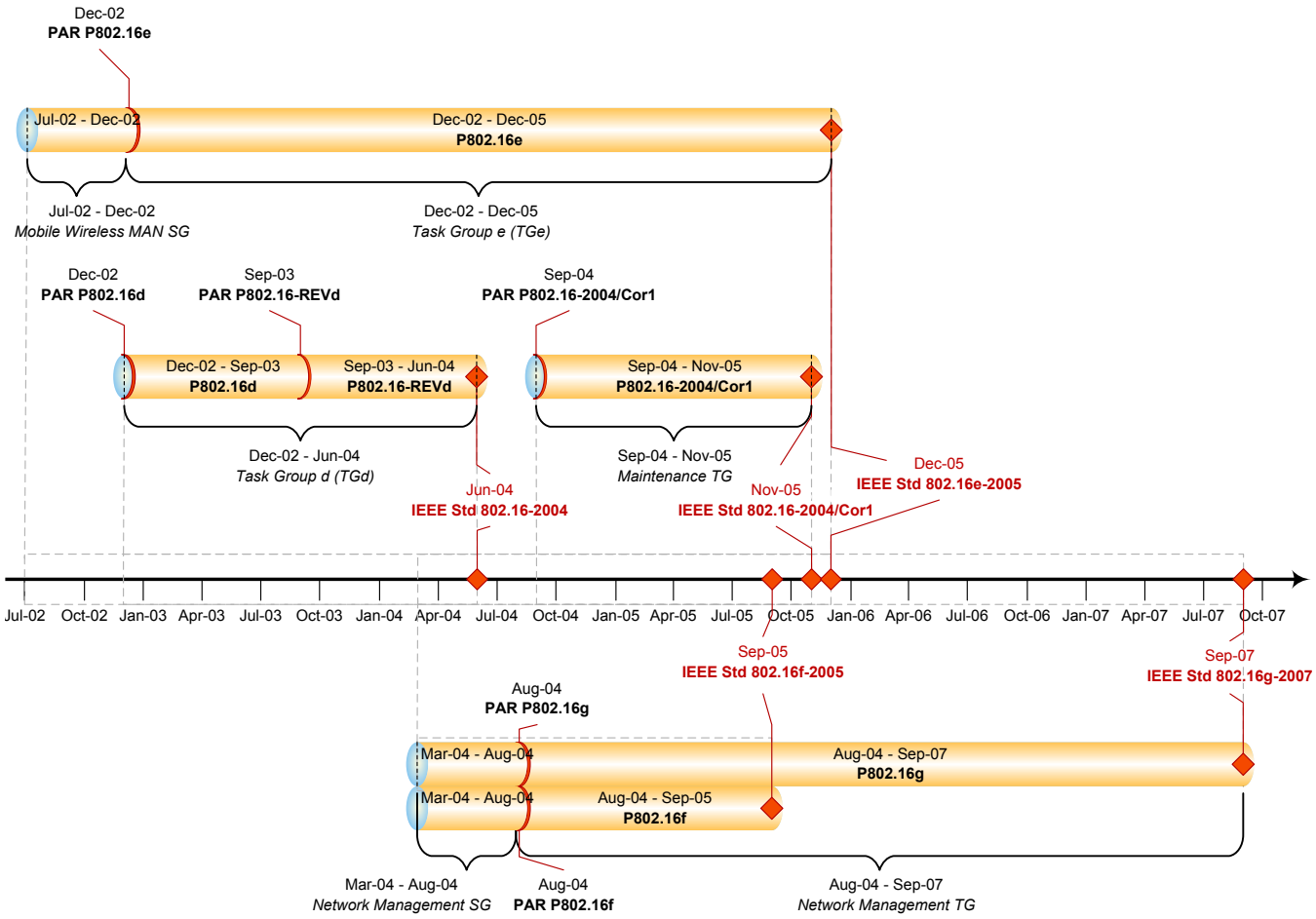

Fig. 4. Timeline with relevant PARs, SGs and TGs for IEEE Std 802.16-2004 and its amendments.

Similar to the merge of P802.16-2004/Cor2 into P802.16Rev2 earlier, the WG agreed in Nov. 2007 to merge the contents of draft D6 of P802.16i within the Network Management TG into the draft of P802.16Rev2 within the Maintenance TG and the P802.16i PAR was subsequently withdrawn in Mar. 2008 [95].

In Jan. 2008, several discussions spotlighted concerns regarding the implications of 802.16j and relay support on the 802.16m network architecture. As a result, the *'16jm' Ad Hoc Group* was instated to study the issues. This Ad Hoc Group delivered its final report [96] in Jul. 2008 as a contribution to TGm.

The IEEE-SASB approved [97] on 13 May 2009 a new revision of IEEE Std 802.16: *IEEE Std 802.16-2009* [98]. Approval was based on the D9a draft of P802.16Rev2, prepared by the Maintenance TG. It was published by IEEE on 29 May 2009. Whereas IEEE Std 802.16-2004 previously obsoleted IEEE Std 802.16-2001 and its amendments (IEEE Std 802.16c-2002 and IEEE Std 802.16a-2003), it now finds itself and its amendments superseded by the latest revision, IEEE Std 802.16-2009. As there was no more interest in a single carrier physical layer for 2-11 GHz frequencies, the WirelessMAN-SCa physical specifications were dropped in this revision and only WirelessMAN-SC, WirelessMAN-OFDM and WirelessMAN-OFDMA remained.

Also on 13 May 2009, draft D9 of P802.16j, developed by the Relay Task Group, was approved [99] by IEEE-SASB as *IEEE Std 802.16j-2009* [100]. The very same day the new revision of IEEE Std 802.16, IEEE Std 802.16-2009, was born, it thus immediately got its first amendment. IEEE Std 802.16j-2009 was published by IEEE on 12 Jun. 2009.

In Nov. 2008, the 802.16 Working Group had approved the creation of an *Ad Hoc Committee on Network Robustness and Reliability (NRR)* with the objective of promoting discussion on robustness and reliability. One year later, in Nov. 2009, the Committee proposed in its final report [101] the creation of the IEEE 802.16 *GRIDMAN Study Group* [102] on 'Greater Reliability In Disrupted Metropolitan Area Networks'. The proposal was approved, putting the SG into effect. The GRIDMAN SG has drafted a PAR [103] for an amendment to IEEE Std 802.16 on Higher Reliability Networks, which was approved on 17 Jun. 2010 by IEEE-SASB as project *P802.16n*. With the GRIDMAN SG's temporary assignment completed, the new *GRIDMAN Task Group* [104] was initiated for drafting a standard in the P802.16n project by enhancing the MAC protocol and extending the WirelessMAN-OFDMA specifications.

As work in P802.16h within the License-Exempt TG had started in Dec. 2004 and still none of its draft documents was expected to make it into an IEEE Standard by the end of

TABLE III
SUMMARY OF THE PROJECTS WITHIN THE IEEE 802.16 WG THAT LED TO IEEE STD 802.16-2004 AND ITS AMENDMENTS.

Project	P802.16d → P802.16-RevD	P802.16-2004/Cor1	P802.16e
Study Group	-	-	Mobile Wireless MAN SG
PAR approval date	Dec. 02	Sep. 04	Dec. 02
Task group	TGd	Maintenance TG	TGe
Purpose	adds 2-11 GHz system profiles → revision project of IEEE Std 802.16-2001 to consolidate amendments	corrects errors in IEEE Std 802.16-2004	adds mobility by making the number of subcarriers in WirelessMAN-OFDMA scalable with the used bandwidth (constant subcarrier spacing)
Project status	completed	completed	completed
Final draft	D5	D5	D12
IEEE-SASB approval date	Jun. 04	Nov. 05	Dec. 05
Publishing date	Oct. 04	Feb. 06	Feb. 06
Standard	IEEE Std 802.16-2004	IEEE Std 802.16-2004/Cor1	IEE Std 802.16e-2005
Standard status	obsoleted	obsoleted	obsoleted

Project	P802.16f	P802.16g
Study Group	NetMan SG	NetMan SG
PAR approval date	Aug. 04	Aug. 04
Task group	NetMan TG	NetMan TG
Purpose	adds MIB for fixed service to facilitate cross-vendor interoperability at the network level for the management of devices	adds Management Procedures and Services for fixed and mobile service to standardize the management plane behaviour
Project status	completed	completed
Final draft	D6	D9
IEEE-SASB approval date	Sep. 05	Sep. 07
Publishing date	Dec. 05	Dec. 07
Standard	IEEE Std 802.16f-2005	IEEE Std 802.16g-2007
Standard status	obsoleted	obsoleted

2008, the project would at that time reach the end of its four-year lifetime (which applies for all PARs). In order for the project to remain active in 2009, the WG therefore requested NesCom a one-year PAR extension of P802.16h in Jul. 2008 [105] (granted in Sep. 2008). One year however seemed to be too short and the PAR was once again extended [106] in Dec. 2009 to remain active in 2010. Then, on 17 Jun. 2010, draft D15 of P802.16h was approved [107] by the IEEE-SASB as *IEEE Std 802.16h-2010* [108] and it was published on 30 Jul. 2010 as the second amendment to IEEE Std 802.16-2009.

In Nov. 2009, the new *Project Planning Ad Hoc group* started to investigate future 802.16 networks challenges and possibilities. In Mar. 2010, the Project Planning Ad Hoc group began drafting a machine-to-machine (M2M) Communications study report and the group was upgraded to be the standing IEEE 802.16 *Project Planning Committee* [109]. In May 2010, the Project Planning Committee concluded the study report and started drafting a PAR for an amendment to IEEE Std 802.16 on Enhancements for Machine-to-Machine (M2M) Communications [110], which was accepted by the IEEE-SASB as project *P802.16p* on 30 Sep. 2010 [111]. The Machine-to-Machine Task Group [112] will manage this project. This amendment builds on top of the features in P802.16m and will support low power operation and small burst transmissions in WirelessMAN-OFDMA and WirelessMAN-Advanced specifications.

Concerning P802.16m, TGm completed its task and draft D12 was approved [113] on 31 March 2011 as *IEEE Std 802.16m-2011*. Publication is expected soon (May 2011).

Thus today (May 2011), only the following IEEE standards that describe the air interface are valid:

- IEEE Std 802.16-2009: IEEE Standard for Local and metropolitan area networks Part 16: Air Interface for Broadband Wireless Access Systems
  - IEEE Std 802.16j-2009: Amendment 1: Multihop Relay Specification
  - IEEE Std 802.16h-2010: Amendment 2: Improved Coexistence Mechanisms for License-Exempt Operation
  - IEEE Std 802.16m-2011: Amendment 3: Advanced Air Interface

Their evolution, as described above, is visualized in Fig. 5 and summarized in Table IV.

Contrary to Fig. 3, Fig. 4 and Fig. 5 which visualized the activities that were preceding each standard's approval, the time succeeding each accepted IEEE 802.16 standard is indicated in Fig. 6. This time line indicates the valid life time of each IEEE 802.16 air interface standard, which ends with the creation of a new revision of the IEEE 802.16 standard.

Besides the completed projects, following projects are ongoing (see Table V), as mentioned before:

- P802.16n: the GRIDMAN Task Group is developing an amendment to IEEE Std 802.16 on Higher Reliability Networks
- P802.16p: the Machine-to-Machine Task Group is developing an amendment to IEEE Std 802.16 on Enhancements to support Machine-to-Machine Applications

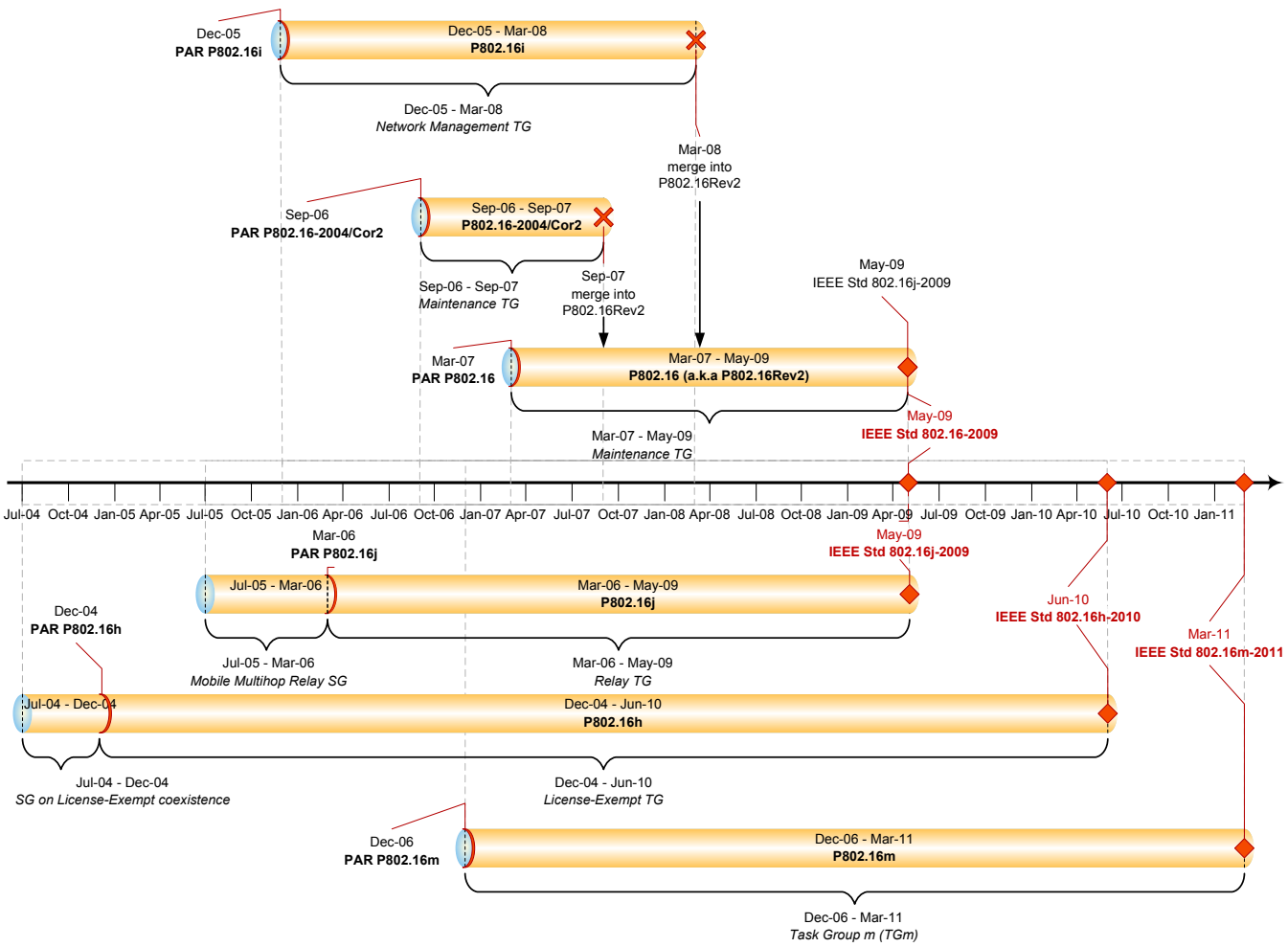

Fig. 5. Timeline with relevant PARs, SGs and TGs for IEEE Std 802.16-2009 and its amendments until now (May 2011).

As for future projects, we would like to inform the reader that preparations are being made within the Project Planning Committee to make a new revision of the IEEE 802.16 standard. This would be the third revision to the original IEEE Std 802.16-2001, succeeding the IEEE Std 802.16-2004 and IEEE Std 802.16-2009 revisions. It would consolidate IEEE Std 802.16-2009, IEEE Std 802.16j-2009, IEEE Std 802.16h-2010 and IEEE Std 802.16m-2011 into a standard document. This will happen in a new *P802.16* project, for which a PAR is being drafted [114]. However, contrary to common practice, IEEE Std 802.16m-2011 would not be completely included in this new revision. Instead, the current idea is to shift the WirelessMAN-Advanced radio interface, which was introduced in this amendment, into a new standalone standard, in addition to the revision standard that is being made. Therefore, another PAR is being drafted for which currently the *P802.16M* project name[10] is suggested [116]. The motivation to split the specifications into two different tracks is to obtain a more practical maintenance of the WirelessMAN-OFDMA air interface on the one hand and of the WirelessMAN-Advanced air interface on the other hand, as each is included in a different ITU (International Telecommunications Union) framework: IMT-2000 and IMT-Advanced, respectively (see Section IV).

The Project Planning Committee also initiated the development of study reports for Hierarchical Networks and for coexistence with non-802 TDD (Time Division Duplex) systems, but the latter topic has been disbanded. Following topics are also on the roadmap of new PARs by the Project Planning Committee for 2011: Enhanced QoS, Ultra High Speed Networks ($>$ 1-5 Gbps) and Green RAN [117].

D. IEEE 802.16 WG other standards

1) Bridging standard: As the IEEE 802.16 WG is part of the 802 family and fits into a general reference model [18], it needs to normalize its compatibility and ensure that it can operate in a bridged IEEE 802 network. Therefore, the WG submitted a new PAR, designated *P802.16k* [118], to amend IEEE Std 802.1D-2004 [119] to specify 802.16 bridging. IEEE Std 802.1D-2004 is a standard of the IEEE 802.1 Working Group (another Working Group within IEEE 802 LMSC) about LAN/MAN Bridging & Management. This PAR was

[10]Normally, the numbering of projects of the same family use a decimal-numbered extension [22]. However, P802.16.1, P802.16.2 and P802.16.3 are/were already used. Calling the standard project P802.16.4 or P802.16.5 "did not sound right" [115] and neither did P802.16.10 or P802.16.20. As the new standard will be based on the IEEE Std 802.16m-2011 amendment, which is well-known, one therefore proposes to make an exception to naming conventions and to use the P802.16M name, with a capital letter 'M' suffix, in order to indicate that the new intended standard descents from the IEEE Std 802.16m-2011 amendment but that it is a standalone standard (as no lower-case letter is used).

TABLE IV
SUMMARY OF THE PROJECTS WITHIN THE IEEE 802.16 WG THAT LED TO IEEE STD 802.16-2009 AND ITS AMENDMENTS.

Project	P802.16h	P802.16i	P802.16j
Study Group	SG on License-Exempt Coexistence	-	MMR SG
PAR approval date	Dec. 04	Dec. 05	Mar. 06
Task group	LE TG	NetMan TG	Relay TG
Purpose	adds Improved Coexistence Mechanisms for License-Exempt Operation to allow sharing of a frequency channel between co-located operators by means of a Coexistence Frame (CX-Frame)	extends the MIB of IEEE Std 802.16f-2005 for mobile service to facilitate cross-vendor interoperability at the network level for the management of devices	adds Multihop Relay Specification for WirelessMAN-OFDMA, by including a transparent zone for RS to MS transmissions in the DL subframe
Project status	completed	merged in P802.16Rev2	completed
Final draft	D15	-	D9
IEEE-SASB approval date	Jun. 10	-	May 09
Publishing date	Jul. 10	-	Jun. 09
Standard	IEEE Std 802.16h-2010	-	IEEE Std 802.16j-2009
Standard status	active (May 2011)	-	active (May 2011)

Project	P802.16-2004/Cor2	P802.16 (P802.16Rev2)	P802.16m
Study Group	-	-	-
PAR approval date	Sep. 06	Mar. 07	Dec. 06
Task group	Maintenance TG	Maintenance TG	TGm
Purpose	correct errors in IEEE Std 802.16-2004 that were not included in IEEE Std 802.16-2004/Cor1	Revision project to consolidate IEEE Std 802.16-2004 and its amendments	adds a WirelessMAN-Advanced air interface for higher throughput and coverage, based on WirelessMAN-OFDMA
Project status	merged in P802.16Rev2	completed	completed
Final draft	-	D9a	D12
IEEE-SASB approval date	-	May 09	Mar. 11
Publishing date	-	May 09	to be determined
Standard	-	IEEE Std 802.16-2009	IEEE Std 802.16m-2011
Standard status	-	active (May 2011)	active (May 2011)

TABLE V
SUMMARY OF THE PROJECTS WITHIN THE IEEE 802.16 WG THAT ARE STILL UNDER DEVELOPMENT TODAY (MAY 2011).

Project	P802.16n	P802.16p
Study Group	GRIDMAN SG	PPC
PAR approval date	Jun. 2010	Sep. 2010
Task group	GRIDMAN TG	M2M TG
Purpose	adds higher reliability by enhancing the MAC protocol and extending WirelessMAN-OFDMA	adds machine-to-machine communication to WirelessMAN-OFDMA and WirelessMAN-Advanced by supporting low power operation and small burst transmissions
Project status	active (May 2011)	active (May 2011)
Final draft	to be determined	to be determined
IEEE-SASB approval date	to be determined	to be determined
Publishing date	to be determined	to be determined
Standard	to be determined	to be determined
Standard status	draft (May 2011)	draft (May 2011)

approved in Mar. 2006 and the Network Management Task Group was chartered for its development. *IEEE Std 802.16k-2007* [120] was approved based on draft D4 in P802.16k on 22 Mar. 2007. It was published on 14 Aug. 2007.

2) Conformance standards: IEEE 802.16's *Task Group C (Conformance) (TGC)* [121] has developed a series of conformance standards, per ISO/IEC Standard 9646-7 (1995) and ITU-T X.296, in support of the the air interface specified in IEEE 802.16. They were published as multipart test documents for conformance to IEEE 802.16:

- *IEEE Std 802.16/Conformance01-2003* [122]: Part 1: Protocol Implementation Conformance Statement (PICS) Proforma for 10-66 GHz WirelessMAN-SC™(Single Carrier) Air Interface. The work was initiated in project P1802.16.1[11] with PAR approval in Aug. 2002, but was renumbered to P802.16/Conformance01 in Jun. 2003 [123]. The standard was approved by IEEE-SASB on 12 Jun. 2003 and published on 18 Aug. 2003.
- *IEEE Std 802.16/Conformance02-2003* [124]: Part 2: Test Suite Structure (TSS) and Test Purpose (TP) for 10-66 GHz WirelessMAN-SC™ Air Interface. The work was initiated in project P1802.16.2 with PAR approval in Dec. 2002, but was renumbered to P802.16/Conformance02 in

[11] Projects for conformance may have parallel numbering to the standard for which conformance is being defined [22]. For the P802.16 project, conformance projects were numbered P**1**802.16.

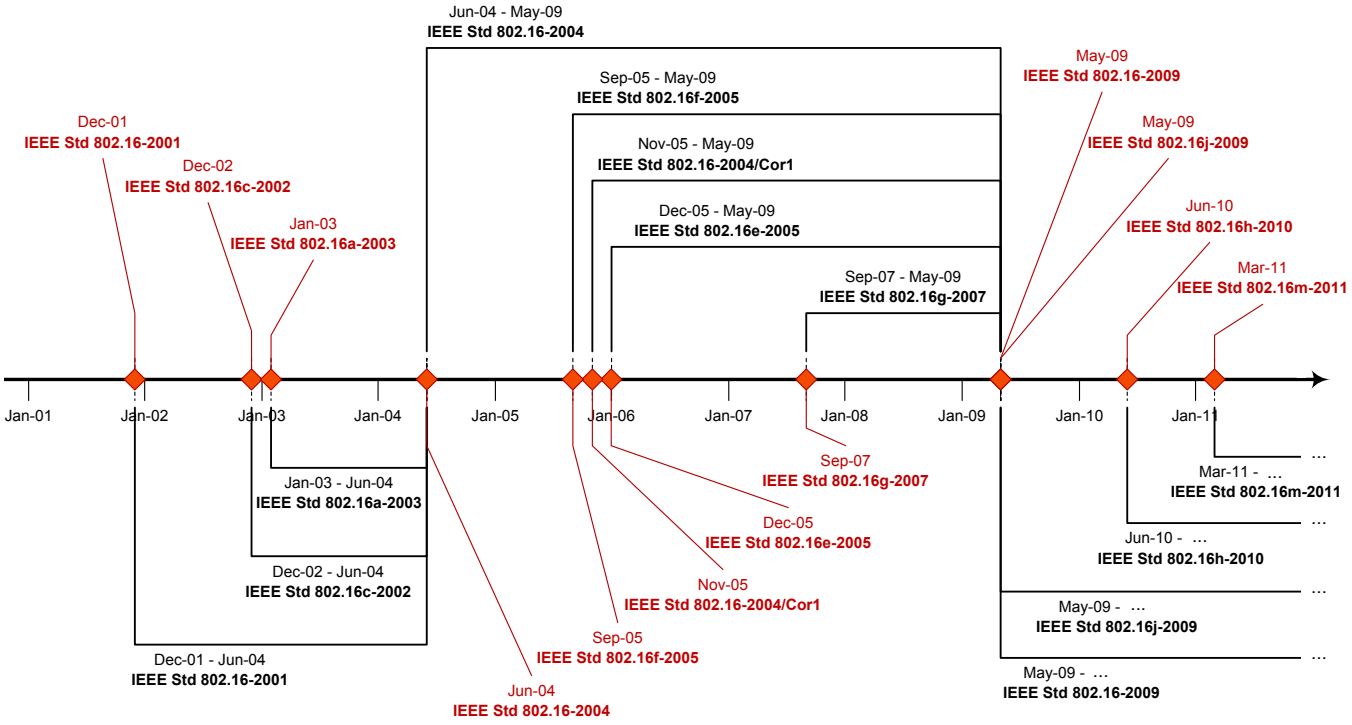

Fig. 6. Timeline revealing the valid lifetime of the IEEE 802.16 air interface standards until now (May 2011)

Jun. 2003 [125]. The standard was approved by IEEE-SASB on 11 Dec. 2003 and published on 25 Feb. 2004.

- IEEE Std 802.16/Conformance03-2004 [126]: Part 3: Radio Conformance Tests (RCT) for 10-66 GHz WirelessMAN-SC™ Air Interface. The work was initiated in project P1802.16.3 with PAR approval in Mar. 2003, but was renumbered to P802.16/Conformance03 in Jun. 2003 [127]. The standard was approved by IEEE-SASB on 12 May 2004 and published on 25 Jun. 2004.
- *IEEE Std 802.16/Conformance04-2006* [128]: Part 4: Protocol Implementation Conformance Statement (PICS) Proforma for Frequencies below 11 GHz. The work was initiated in project P802.16/Conformance04 with PAR approval in Mar. 2004 [129]. The standard was approved by IEEE-SASB on 15 Sep. 2006 and published on 15 Jan. 2007.

IEEE Std 802.16/Conformance01-2003, IEEE Std 802.16/Conformance02-2003 and IEEE Std 802.16/Conformance03-2004 applied to the WirelessMAN-SC physical layer specifications at 10-66 GHz of IEEE Std 802.16-2001 and were administratively withdrawn after a five-year lifespan. No revision nor reaffirmation was made, as there was not enough interest in those higher frequencies any longer. Only IEEE Std 802.16/Conformance04-2006 is still active and concerns conformance testing to fixed systems with WirelessMAN-OFDM or WirelessMAN-OFDMA physical layer specifications conform IEEE Std 802.16-2004 (although this air interface standard itself is now obsoleted by IEEE Std 802.16-2009, as discussed previously).

3) Coexistence standards: Within the IEEE 802.16 WG that was created after the PAR P802.16 approval in Mar. 1999, a *Co-existence Task Group* [29] (later known as *Task Group 2 (TG2)*) was created. They submitted a PAR [28] in Jul. 1999 for a Recommended Practice about Coexistence of Broadband Wireless Access Systems, which was approved by IEEE-SASB in Sep. 1999 as *P802.16.2*.

In Mar. 2001 it was intended to bring all projects into a single 802.16 standard and the renumbering of among others P802.16.1 to P802.16 [39] took place (see Section II-C). However, the P802.16.2 project number did not fit in. Since this document is a Recommended Practice, it could not be published as part of a Standard. Therefore, P802.16.2 was not renumbered[12]. One did however slightly change the scope of P802.16.2 [38], [130]. The changes included among others the explicit choice for 10-66 GHz and interference with satellite systems was no longer considered.

Draft D3 of P802.16.2 was approved as *IEEE Std 802.16.2-2001* [131] in Jul. 2001 [132] and published in Sep. 2001. This was actually the first resulting IEEE standard of the IEEE 802.16 WG (even before the first air interface standard IEEE Std 802.16-2001, see Section II-C).

In Aug. 2001 the PAR was approved for project *P802.16.2a* [133] of TG2, which envisaged an amendment to IEEE Std 802.16.2-2001 for the 2-11 GHz frequency range (similar as P802.16a to IEEE Std 802.16-2001, see Section II-C). In Sep. 2003, P802.16.2a was converted into *P802.16.2-REVa* [134] to make it a revision project of IEEE Std 802.16.2 rather than an amendment (similar to the conversion of P802.16d into P802.16-REVd which was approved on the same date, see Section II-C). Draft D8 of P802.16.2-REVa resulted on 9 Feb. 2004 in a new revision of the standard: *IEEE Std 802.16.2-*

[12]A suggestion to renumber P802.16.2 to P802.16RP was rejected [38].

2004 [135] and it was published on 17 Mar. 2004. As its 5 year lifespan became expired, its validity was reaffirmed [136] in Feb. 2010 for another 5 year.

E. Summary of active standards

To summarize, only the following standards are still active today (May 2011):

- IEEE Std 802.16-2009 [98]
  - IEEE Std 802.16j-2009 [100]
  - IEEE Std 802.16h-2010 [108]
  - IEEE Std 802.16m-2011 [137]
- IEEE Std 802.16k-2007 [120]
- IEEE Std 802.16.2-2004 [135]
- IEEE Std 802.16/Conformance04-2006 [128]

III. The role of WiMAX Forum ®

Within this section, the activities of the WiMAX Forum are described. This organization certifies equipment that is compliant with the parameter values they have chosen in the IEEE 802.16 standards to assure device interoperability. The WiMAX Forum is introduced in Section III-A and the benefits of a certification label are described in Section III-B. The system profiles that are derived from IEEE 802.16 are explained in Section III-C, while information on the different succeeding releases and their development can be read in Section III-D. The process for a vendor's product to be certified is finally given in Section III-E.

A. About the organization

The WiMAX Forum is an industry-led, not-for-profit organization which has hundreds of members, comprising most of the WiMAX operators, component vendors and equipment vendors. It was established in Jun. 2001 to promote and certify wireless broadband equipment based on the IEEE 802.16 and ETSI HiperMAN (European Telecommunications Standards Institute High Performance Metropolitan Area Networks) standards[13] by awarding equipment manufacturers' products with the 'WiMAX Forum Certified' label (Worldwide Interoperability for Microwave Access). Note that this role is thus comparable to what the Wi-Fi Alliance is doing for the IEEE 802.11 standards.

We can distinguish three functional areas of development within the WiMAX Forum:

- *air interface specifications* focus on the first and second layer of the OSI reference model [19] and are based on IEEE 802.16 (see Fig. 7),
- *network specifications* apply to the upper layers and are not based on IEEE 802.16 but developed within the WiMAX Forum (see Fig. 7),
- *roaming specifications* deal with the Roaming Business Framework with functions for wholesale rating, etc.

Different tasks within the WiMAX Forum are divided between following working groups [138]:

[13]The HiperMAN specifications are being developed by the Technical Committee Broadband Radio Access Networks (BRAN) within ETSI. They focus on frequency bands below 11 GHz and are developed in cooperation with the IEEE 802.16 WG.

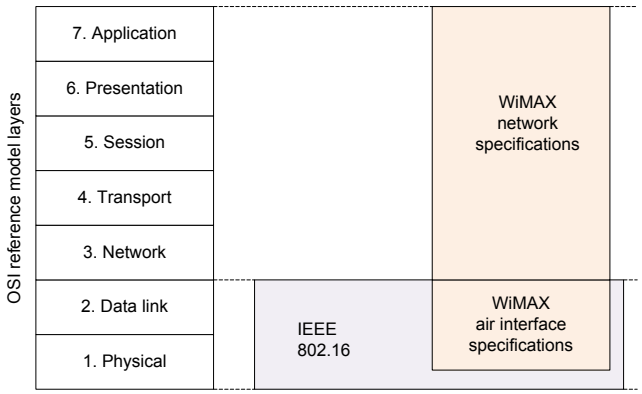

Fig. 7. Relationship between IEEE 802.16 and WiMAX, with respect to the OSI reference model [19].

- Technical Steering Committee (TSC)
- Service Provider Working Group (SPWG): Gives service providers a platform for influencing BWA product and spectrum requirements to ensure that their individual market needs are fulfilled.
- Network Working Group (NWG): Creates higher level networking specifications for fixed, nomadic, portable and mobile WiMAX systems, beyond what is defined in the scope of IEEE 802.16.
- Technical Working Group (TWG): The main goal of the TWG is to develop technical product specifications and certification test suites for the air interface based on OFDMA, complementary to the IEEE 802.16 standards, primarily for the purpose of interoperability and certification of Mobile Stations, Subscriber Stations and Base Stations conforming to the IEEE 802.16 standards.
- Certification Working Group (CWG): Handles the operational aspects of the WiMAX Forum Certified program.
- Global Roaming Working Group (GRWG): Assures the availability of global roaming service for WiMAX networks in a timely manner as demanded by the marketplace.
- Regulatory Working Group: Influences worldwide regulatory agencies to promote WiMAX-friendly, globally harmonized spectrum allocations.
- Marketing Working Group (MWG): Drive worldwide adoption of WiMAX enabled wireless broadband connectivity anytime, anywhere.
- Smart Grid Working Group (SGWG): Provides marketing support to position WiMAX in the Utility Industry and maximize participation in this market segment.

B. Benefits of certification

Simply being IEEE 802.16-compliant does not guarantee that equipment from one vendor will interoperate with equipment from another vendor as they could each have implemented different subsets of the standard. Should each vendor implement the complete IEEE 802.16 standard (the same revision with the same amendments), the latter problem would be solved. However, as the IEEE 802.16 standard is quite broad, this implementation would require a huge

amount of effort and would therefore be too expensive [11]. An intermediate organization, i.e. the WiMAX Forum, which specifies a subset of the IEEE 802.16 standard for vendors to comply to, is much more feasible and cost effective to guarantee equipment interoperability.

The WiMAX Forum cannot explicitly oblige the vendors to have their products certified. A vendor can make a system with a different subset of the IEEE 802.16 standard (than the one specified by the WiMAX Forum), or even with the same subset but neglecting to certify his products by the WiMAX Forum. However, end users are looking for 'WiMAX equipment' and not for 'some IEEE 802.16 equipment' (they have probably even never heard of IEEE 802.16) but 'Mobile WiMAX', 'Fixed WiMAX', the WiMAX Forum logo, etc. are trademarks of the WiMAX Forum. Thus, if the vendor wants to use the 'WiMAX Forum Certified' label for its product, it needs permission of the WiMAX Forum, to prevent legal proceedings for trademark infringement. The WiMAX Forum only grants this permission, if the vendor's product is certified by the WiMAX Forum [139] (see Section III-E).

Therefore, the vendors themselves are willing to certify their products to obtain this label, without any external obligation as this has many benefits for vendors, network operators and end users [11], [140]:

1) Benefits for vendors:

- Faster innovation: there is no need to focus on a complete end-to-end product line, as with proprietary broadband wireless access systems. Vendors can specialize in specific components, allowing faster development cycles.
- Cost improvement: specialization in specific component can lead to lower-cost modules which can be integrated in the vendor's devices.
- Faster troubleshooting: interoperability problem detection before commercialization.
- Easier targeting of the global market: the certification label has a worldwide reputation.

2) Benefits for network operators:

- Easy deployments: there is no vendor lock-in and a multi-vendor network can be deployed in a more cost effective and faster way.
- Support of any subscriber device: all certified end devices (with the same certification profile) are instantly supported, as well as roaming support for end devices that originate from another network operator (with the same certification profile).
- Backward compatibility: certified products are guaranteed to be backward compatible.

3) Benefits for end users:

- Increased confidence: the purchased certified product will certainly work with any network operator that uses certified products (with the same certification profile).
- User mobility: the end user can use the same device when switching to or roaming on the network of another network operator.
- Cheaper devices: higher volumes and more competition are possible by economy of scale, which lowers the price of the devices.

TABLE VI
SYSTEM PROFILES FOR WIRELESSMAN-SC [65].

Current name	Spectrum (GHz)	BW (MHz)	Duplexing mode
profP1f	10-66	25	FDD
profP1t	10-66	25	TDD
profP2f	10-66	28	FDD
profP2t	10-66	28	TDD

C. WiMAX profiles

Based on the IEEE 802.16 and ETSI HiperMAN standards, the WiMAX Forum develops *system profiles*, which define mandatory and optional capabilities for WiMAX products. The list of features tested in system profiles is more stringent than the underlying standards (features that are optional in the standards may be tested as mandatory by the WiMAX Forum Certified™ program), but does not include any new feature that is not included in the standards [141].

Initially, the WiMAX Forum focused on the 10-66 GHz frequencies in the WirelessMAN-SC physical layer specifications of IEEE Std 802.16-2001 (see Section II-C). The WiMAX Forum collaborated on the IEEE Std 802.16c-2002 amendment to develop the system profiles for WirelessMAN-SC, which are shown in Table VI.[14]

Next, the WiMAX Forum helped developing IEEE Std 802.16/Conformance01-2003, IEEE Std 802.16/Conformance02-2003 and IEEE Std 802.16/Conformance03-2004 for a Protocol Implementation Conformance Statement (PICS) Proforma, Test Suite Structure (TSS) and Test Purpose (TP) and Radio Conformance Test (RCT), respectively (see Section II-D). Those documents are in accordance with ISO/IEC Standard 9646-7 (1995) and ITU-T X.296 which specify how to write test documentation. The next step would be to develop an Abstract Test Suite (ATS) document, which includes detailed test procedures, but this never happened as industry interest was shifting towards lower frequencies. No products could thus be certified for a 10-66 GHz profile.

IEEE Std 802.16/Conformance04-2006 was created to develop the PICS for the lower frequencies, but the WiMAX Forum now elaborated the system profiles and responding documents for those lower frequencies within its own organization, outside the IEEE 802.16 WG. Within the WiMAX Forum, there are currently two system profiles:

- the *Fixed WiMAX* system profile for systems based on IEEE Std 802.16-2004 [65] using the WirelessMAN-OFDM physical layer specifications with 256 carriers
- the *Mobile WiMAX* system profile for systems that are based on the IEEE Std 802.16e-2005 [80] amendment using the WirelessMAN-OFDMA physical layer specifications

An indication of some Mobile WiMAX system profile parameter values [142] compared to the values that are specified in IEEE Std 802.16-2009 [98] is given in Table VII.

[14]Note that one actually differentiates between physical and MAC profiles and that two different MAC profiles had also been specified for WirelessMAN-SC: profM1 and profM2.

TABLE VII
SOME KEY IEEE STD 802.16-2009 PARAMETERS VALUES AND THE SUBSET OF VALUES THAT ARE MANDATORY IN MOBILE WIMAX RELEASE 1.5, INDICATED IN BOLD.

Parameter	IEEE Std 802.16-2009 and **Mobile WiMAX Release 1.5** values
Air interface	WirelessMAN-SC, WirelessMAN-OFDM, **WirelessMAN-OFDMA**, WirelessHUMAN
Cyclic prefix	1/4, **1/8**, 1/16, 1/32
Frame length [ms]	2, 2.5, 4, **5**, 8, 10, 12.5, 20
Convolutional code	**Tail biting**, Zero tail
Downlink modulation	**QPSK, 16-QAM, 64-QAM**
Uplink modulation	**QPSK, 16-QAM**, 64-QAM

TABLE VIII
FIXED WIMAX PROFILES WITH THEIR PROPERTIES AND CURRENT AND PAST NAMING CONVENTIONS. PROFILES THAT HAVE PRODUCTS CERTIFIED AGAINST, ARE INDICATED IN BOLD.

Old name	Alternative name	Current name	Spectrum (GHz)	BW (MHz)	Duplexing mode
Air 1	**3.5T2**	**ET01**	**3.5**	**3.5**	**TDD**
Air 2	**3.5F1**	**ET02**	**3.5**	**3.5**	**FDD**
Air 3	3.5T1	N.A.	3.5	7	TDD
Air 4	3.5F2	N.A.	3.5	7	FDD
Air 5	5.8T	N.A.	5.8	10	TDD

Different *certification profiles* are derived out of each system profile. They limit the number of WiMAX implementations allowed under a system profile, as a certification profile additionally defines three parameters: spectrum band (e.g. 3.5 GHz, 2.5 GHz, etc.), channel size (e.g. 5 MHz) and duplexing mode (Frequency Division Duplex (FDD) or Time Division Duplex (TDD)). Those parameters mostly depend on the local regulatory requirements. By complying to the same certification profiles, interoperability between products of different vendors is guaranteed.

Multiple certification profiles will be required to comply with different regulatory requirements that different operators need to adhere to. On the other hand, however, if there are too many certification profiles, the market could become fragmented and threaten interoperability. A trade off is thus to be made for the number of certification profiles.

The first certification profiles were the 'fixed profiles' based on the Fixed WiMAX system profile and are listed in Table VIII [140], [143], [144]. Fixed WiMAX certification profiles were originally numbered sequentially as Air 1, Air 2, Air 3, Air 4 and Air 5. Later, they were renamed to 3.5T2, 3.5F1, 3.5T1, 3.5F2 and 5.8T, respectively. However, Fixed WiMAX products have only been certified against 3.5T2 (Air 1) or 3.5F1 (Air 2). Those profiles are now known as ET01 and ET02, respectively. They are indicated in bold in Table VIII.

The 'mobile' certification profiles based on the Mobile WiMAX system profile, which has the most commercial interest to date (see Section V), are listed in Table IX, as currently defined by the CWG [140], [143]–[145]. Note that not every certification profile has yet been precisely defined, notably for those within the 700 MHz spectrum. The profiles in Table IX are listed according to current naming conventions, which include the center frequency and a T/F letter (indicating TDD or FDD) within the profile's name (e.g. M2500T-01). Previously, only a subset of the current profiles was considered

TABLE IX
MOBILE WIMAX PROFILES WITH THEIR PROPERTIES AND CURRENT AND PAST NAMING CONVENTIONS. PROFILES THAT HAVE PRODUCTS CERTIFIED AGAINST, ARE INDICATED IN BOLD.

Current name	Old name	BCG	Spectrum (GHz)	BW (MHz)	Duplexing mode
M2300T-01	**MP01**	**1.A**	**2.3 - 2.4**	**8.75**	**TDD**
M2300T-02	**MP02**	**1.B**	**2.3 - 2.4**	**5 & 10**	**TDD**
M2300T-03	N.A.	2.A	2.305 - 2.320, 2.345 - 2.360	3.5	TDD
M2300T-04	MP03	2.B	2.305 - 2.320, 2.345 - 2.360	5	TDD
M2300T-05	MP04	2.C	2.305 - 2.320, 2.345 - 2.360	10	TDD
M2300T-06	N.A	N.A	2.305 - 2.320, 2.345 - 2.360	5 & 10	TDD
M2300F-07	N.A.	2.D	2.305 - 2.320, 2.345 - 2.360	2x3.5	FDD
M2300F-08	N.A.	2.E	2.305 - 2.320, 2.345 - 2.360	2x5	FDD
M2300F-09	N.A.	2.F	2.305 - 2.320, 2.345 - 2.360	2x10	FDD
M2500T-01	**MP05**	**3.A**	**2.496 - 2.690**	**5 & 10**	**TDD**
M2500F-02	N.A.	3.B	2.496 - 2.572, 2.614 - 2.690	2x5 or 2x10	FDD
M3300T-01	MP06	4.A	3.3 - 3.4	5	TDD
M3300T-02	MP07	4.B	3.3 - 3.4	7	TDD
M3300T-03	N.A.	4.C	3.3 - 3.4	10	TDD
M3500T-01	MP08	5.A	3.4 - 3.8	5	TDD
M3700T-01	N.A.	5.AH	3.6 - 3.8	5	TDD
M3500T-02	**MP09**	**5.AL**	**3.4 - 3.6**	**5**	**TDD**
M3700T-02	N.A.	5.B	3.4 - 3.8	7	TDD
M3700T-03	N.A.	5.BH	3.6 - 3.8	7	TDD
M3500T-03	**MP10**	**5.BL**	**3.4 - 3.6**	**7**	**TDD**
M3500T-04	MP11	5.C	3.4 - 3.8	10	TDD
M3700T-04	N.A.	5.CH	3.6 - 3.8	10	TDD
M3500T-05	**MP12**	**5.CL**	**3.4 - 3.6**	**10**	**TDD**
M1700F-01	N.A.	6.A	1.710 - 1.755, 2.110 - 2.155	2x5 or 2x10	FDD
M0700F-01	N.A.	7.A	0.776 - 0.787, 0.746 - 0.757	2x5 or 2x10	FDD
M0700F-02	N.A.	7.B	0.788 - 0.793, 0.793 - 0.798 0.758 - 0.763, 0.763 - 0.768	2x5	FDD
M0700F-03	N.A.	7.C	0.788 - 0.798, 0.758 - 0.768	2x10	FDD
M0700F-04	N.A.	N.A.	'700 MHz'	2x5 / 2x7 / 2x10	FDD
M0700T-04	N.A.	7.D	0.698 - 0.746	5 / 10	TDD
M0700T-05	N.A.	7.E	0.746 - 0.806	5 / 10	TDD
M0700T-06	N.A.	7.F	0.790 - 0.862	5 / 10	TDD
M0700T-07	N.A.	N.A.	'700 MHz'	7	TDD
M0700T-08	N.A.	N.A.	'700 MHz'	5 / 7 / 10	TDD

and profiles were numbered sequentially (e.g. M2500T-01 was known as MP05). Alternatively, certification profiles were also referred to by a 'Band Class Certification Group (BCG)'. Those past naming convention are listed in Table IX for the sake of completeness, where they are related to the current profiles. While the list of profiles in Table IX is quite extensive, only a subset of the current profiles are 'active', meaning that they have ongoing certification testing and announced certified products. Those certification profiles are M2300T-01, M2300T-02, M2500T-01, M3500T-02, M3500T-03 and M3500T-05 and are indicated in bold in Table IX. Testing for a non-active profile can start as soon as at least three vendors are ready to validate this profile [140]. Certificates of Mobile WiMAX products include a CRSL version number, indicating what test suites the product was certified against (see Section III-E). An example of a Mobile WiMAX product certificate is shown in Fig. 8.

D. WiMAX releases

In order to gradually certify additional features, different 'releases' and different 'waves' within a release were introduced. Certified equipment is backward compatible with equipment tested under previous releases and waves.

For Fixed WiMAX, only one release with two waves has been specified. There were no further releases, as the focus shifted sharply from Fixed WiMAX towards Mobile WiMAX, which is being actively developed and deployed. Note that Mobile WiMAX can of course also be used for fixed or nomadic access.

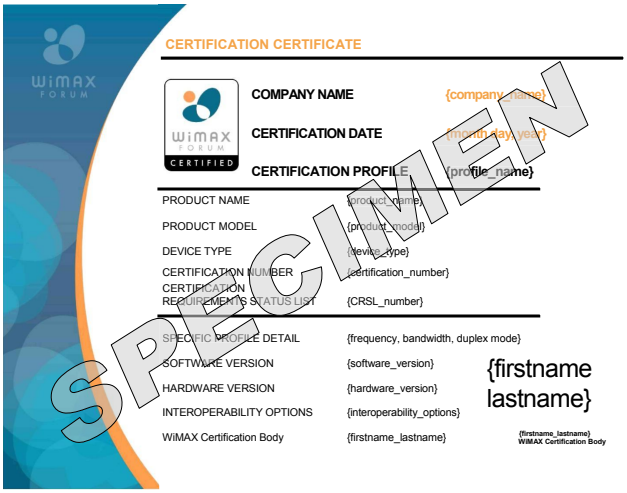

Fig. 8. Example of a Mobile WiMAX certificate

As interest in Mobile WiMAX was growing, the development of an elaborate framework for the development of new releases was set up for Mobile WiMAX in *the WiMAX Forum Certified™ program*. Within the program, the WiMAX Forum develops the specifications that equipment manufacturers need to adhere to for their products to receive a certificate and the 'WiMAX Forum Certified' label.

The Mobile WiMAX release development process is partitioned in six stages and is shown in Fig. 9 [146]. In the first stage, requirements are written by the Service Provider Working Group (SPWG). Stage 2 till 5 are dealt with by the Technical Working Group (TWG), Network Working Group (NWG) and Global Roaming Working Group (GRWG) for drafting the air interface, network and roaming specifications respectively. Finally, in stage 6 certification procedures are derived by the CWG for implementation and validation. A complete iteration through all those stages can produce a new *Release*. The documents that are produced during those stages have a unique number [147] that reflects their functional area of development, the development stage and the release number as explained in Table X.

Release 1.0 is based on IEEE Std 802.16-2004 [65] and IEEE Std 802.16e-2005 [80] and the parameters are described in the 'Mobile System Profile Release 1.0 Approved Specifications' [148] document. Revision 1.2.2 (2006/11/17) of this document was used by the ITU to derive the IMT-2000 OFDMA TDD WMAN (Wireless Metropolitan Area Network) interface from (see Section IV), as specified in their M.1457-7 [149] document. On its turn, the WiMAX Forum then used the latter document to generate its 'WiMAX Forum Mobile System Profile: Release 1 IMT-2000 Edition' final document (WMF-T23-007-R010v02) [148] for Release 1.0.

Release 1.5 is an expansion of Release 1.0 as it is based on the new IEEE revision: IEEE Std 802.16-2009 [98]. It also introduces FDD certification profiles besides TDD profiles The air interface of release 1.5 is described in documents WMF-T23-001-R015v01 [142], WMF-T23-002-R015v01 [150] and WMF-T23-003-R015v01 [151]. Note that for the network specifications, a Release 1.6 has also been specified, using

TABLE X
WiMAX Forum document numbering [147].

WMF-[Lnm]-[bbb]-R[rrr]v[vv]	
Ln	Nature and focus area of the document:
	A1 Administrative aspects
	C1 Certification aspects
	M1 Marketing aspects
	T1 Technical: Deployment & application
	T2 Technical: Air interface aspects
	T3 Technical: Network aspects
	T4 Technical: Roaming aspects
m	Stage of the document:
	1 Requirements
	2 Architecture
	3 Profiles, protocols
	4 Conformance
	5 Test procedures
	6 Certification
bbb	Three digit identification number
rrr	Release number (if applicable):
	010 Release 1.0
	015 Release 1.5
	016 Release 1.6
	020 Release 2.0
vv	Document version number

the Release 1.5 air interface, which included some network improvements, including support for e.g. IPv4/IPv6 transition and femto cells.

Release 2.0 will incorporate parameter values for the IEEE Std 802.16m-2011 MAC and PHY layer (WirelessMAN-Advanced) enhancements and is expected for 2011. It will be developed to fulfillment of IMT-Advanced requirements [146], see Section IV. The *WiMAX 2 Collaboration Initiative (WCI)* is an initiative which started among a small group of vendors working together to accelerate interoperability of future WiMAX Release 2 products. The development timeline for Release 2 targets early engineering trials by mid-2011, with WiMAX Forum certification of equipment by the end of 2011, early commercial availability by mid-2012, and general commercial availability with rich terminal offerings in 2013.

E. The certification process

Vendors need to submit their product to a testing lab in order to be eligible for the 'WiMAX Forum Certified' label. The WiMAX Forum establishes the test suites and selects the testing labs, known as *WiMAX Forum Designated Certification Labs (WFDCLs)*[15]. The final nomination of those labs is sanctioned by the CWG and approved by the WiMAX Forum Board of Directors. Currently, there are 6 certification labs [152]:

- AT4 Wireless - USA & Spain[16]
- Bureau Veritas ADT - Taiwan
- CATR - China

[15]Besides WFDCLs, there also exist WiMAX Forum Designated Validation Laboratories (WFDVLs) which validate testing platforms to meet the requirements of the WiMAX Forum.

[16]WiMAX certification activities in Spain have ceased since early 2011.

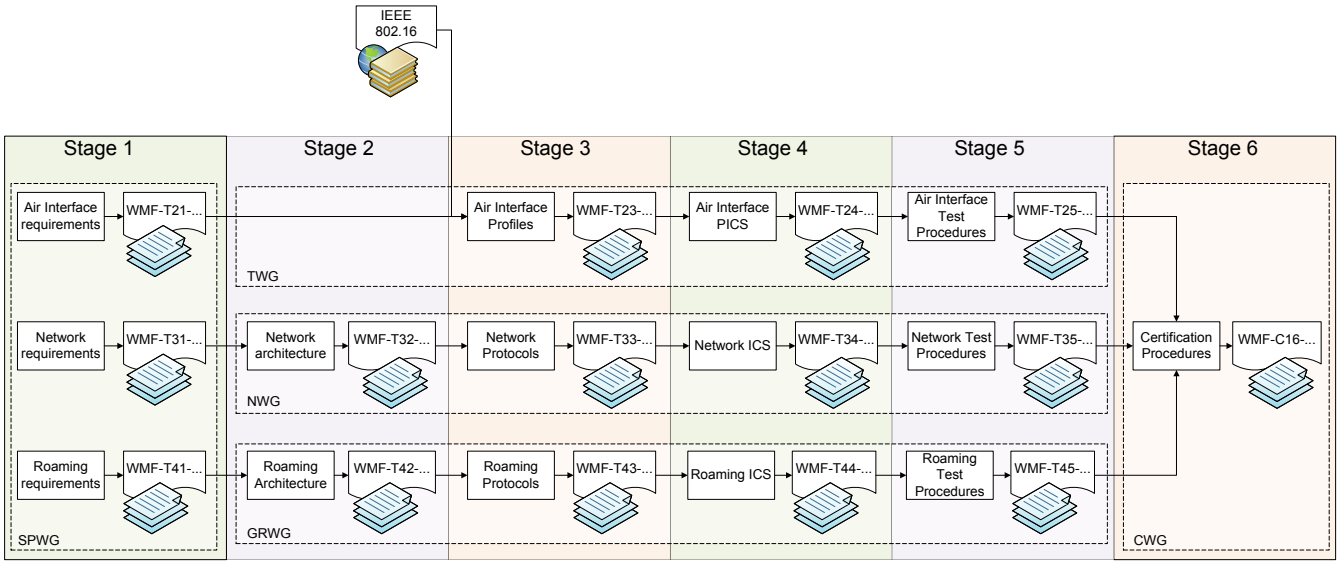

Fig. 9. Simplified flow chart of the Mobile WiMAX release development process.

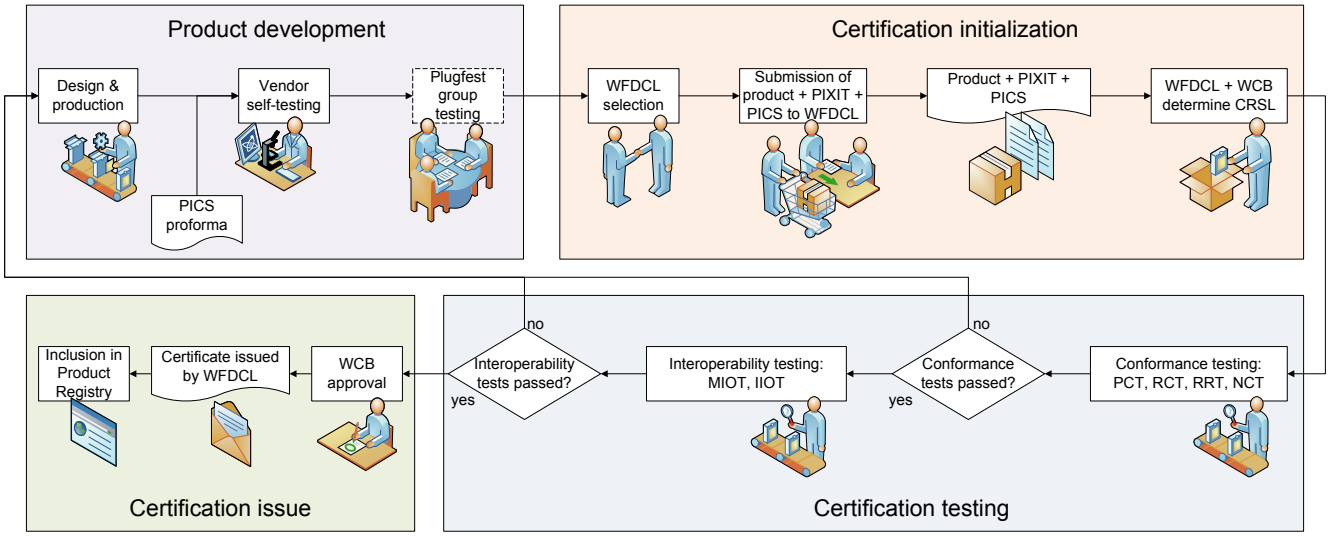

Fig. 10. Simplified flow chart of the WiMAX Forum certification process.

- SIRIM QAS International - Malaysia
- TTA - South Korea
- TTC - Taiwan

The actual testing is done by the testing labs without the direct involvement of the WiMAX Forum. The certification process is depicted in Fig. 10. It starts for a product (a device or a module) when the vendor selects a WFDCL and one or more certification profiles for the product. The product will be tested separately for each certification profile it claims to support. When the equipment is submitted, the testing lab requires the vendor to also submit the *Protocol Implementation Conformance Statement (PICS)* and a *Protocol Implementation Extra Information for Testing (PIXIT)*. The PICS document is actually a completed questionnaire that is filled in by the vendor. The empty questionnaire was fournished by the WiMAX Forum and is known as the *PICS Proforma* [153]. The PICS states that the vendor supports all capabilities to be tested during the certification process and that the product meets the certification requirements. The PIXIT document provides information on the equipment configuration, plus additional information on the product [140].

The lab then identifies the test suites relevant to the submitted product, based on the equipment submission materials and the *Certification Requirements Status List (CRSL)*, which dictates the complete set of required testing at a given time [140]. Currently it requires Protocol Conformance Testing (PCT), Radio Conformance Testing (RCT), Network Conformance Testing (NCT), Radio Regulatory Testing (RRT), Mobile Interoperability Testing (MIOT) and Infrastructure Inter-Operator Testing (IIOT) [140]. RCT, PCT, and MIOT are based on the IEEE 802.16 and the ETSI HiperMAN standards, and exclusively target MAC (Medium Access Control) and

PHY (physical) layer capabilities. NCT and IIOT are based on the WiMAX Forum Network specifications and target upper layers.

If any test fails, the certification testing is halted and the vendor is asked to make the needed changes and to restart the certification process. If all tests are completed successfully, the *WiMAX Certification Body (WCB)* reviews the results. The WCB is a set of individuals that review and verify all WFDCL certification test results and manufacturer declarations against the requirements and make the final certification decision. When the WCB acknowledges the product certification, the WFDCL issues the certificate and the product is added to the *WiMAX Forum Certified Product Registry* [140].

Besides this formal procedure, the WiMAX Forum also sponsors *Plugfests* [154], [155]. Those are group tests during one week where vendors can informally test their equipment with that of other vendors ahead of formal certification testing, which can lead to a shorter time to market when the certification process has come effective.

IV. The role of ITU

Within this section, we discuss the International Telecommunication Union (ITU) and the role of the WiMAX Forum and the IEEE 802.16 WG therein. The ITU is introduced in Section IV-A. IMT-2000 is an important framework for worldwide wireless access and is described in Section IV-B. IEEE 802.16 WG managed to add an air interface to IMT-2000 and this is described in Section IV-C. The benefits thereof are stated in Section IV-D. Next, we described IMT-Advanced, the successor of IMT-2000, in Section IV-E, as well as how the IEEE 802.16 WG remains involved in this program, in Section IV-F. As IMT-Advanced is linked to 4G terminology, we finally explain this in Section IV-G.

A. About the organization

The International Telecommunication Union (ITU) was established in 1865 in Paris as the International Telegraph Union and is now the United Nations agency for information and communication technology issues, based in Geneva, Switzerland [156]. Today, ITU's mission is to enable the growth and sustained development of telecommunications and information networks, and to facilitate universal access so that people everywhere can participate in, and benefit from, the emerging information society and global economy [157]. There are three sectors within the ITU: ITU-R (Radiocommunication), ITU-T (Telecommunication) and ITU-D (Development). Both governments and private organizations can apply for ITU membership. The former will be 'Member States' while the latter will be 'Sector Members' (full membership within a specific ITU sector) or 'Associates' (membership for a specific Study Group within an ITU sector). IEEE has become a Sector Member in the ITU-R, as of 31 Oct. 2003.

Within the ITU-R there are different *Study Groups (SG)*, which use among others the following document types [158]:

- The *Resolutions* give instructions on the organization, methods or programmes of Radiocommunication Assembly (RA) or Study Group work.

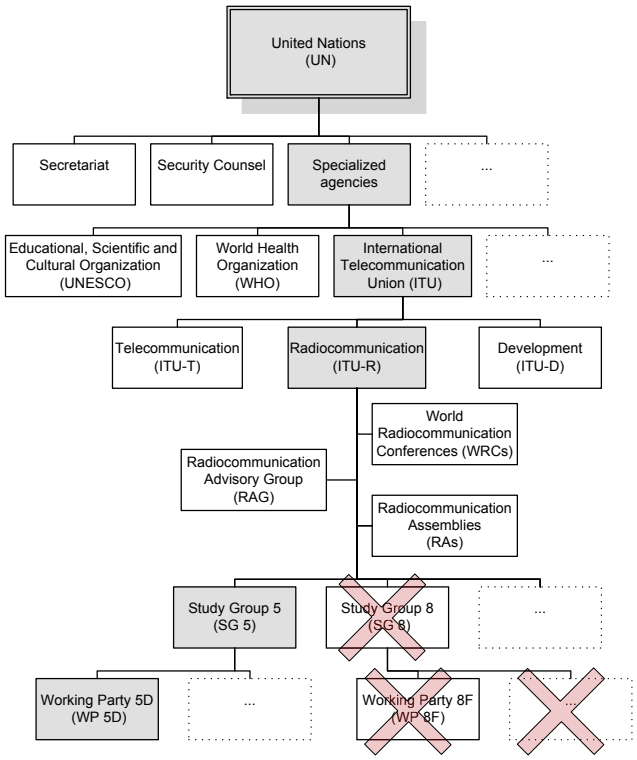

Fig. 11. Reduced hierarchical view on the ITU, showing only the most relevant entities with IEEE 802.16 WG involvement concerning IMT-2000 and IMT-Advanced.

- A *Question* is a statement of a technical, operational or procedural problem, generally seeking a Recommendation.[17] It is a first-stage document which defines what kind of studies and on which subject a Study Group is expected to study.
- The *Recommendations* constitute a set of international technical standards. They are the result of studies undertaken by Radiocommunication Study Groups. The ITU-R Recommendations are approved by ITU Member States. Their implementation is not mandatory; however, they are highly valued and are implemented worldwide.

As the Study Groups study different ITU-R Questions, a SG is typically subdivided into different *Working Parties (WP)*.

Radiocommunication Assemblies (RA) are responsible for the structure, programme and approval of the radiocommunication studies. They are normally convened every three or four years. The Assemblies can among others approve and issue ITU-R Recommendations and ITU-R Questions developed by the Study Groups, set the programme for Study Groups, and disband or establish Study Groups according to need. The *Radiocommunication Advisory Group (RAG)* is authorized (in accordance with Resolution ITU-R 52) to act on behalf of the Assembly in the period between Assemblies. Radio regulation issues are dealt with in World Radiocommunication Conferences (WRCs).[18] A simplified hierarchical view on the ITU is shown in Fig. 11.

[17] Alternatively, a Question could also be answered in a Handbook or Report

[18] Before 1993, WRCs were known as WARCs (World Administrative Radio Conference).

B. IMT-2000

International Mobile Telecommunications-2000 (IMT-2000)[19] is the program of the ITU for third generation (3G) wireless communications, defined in 2000 by a set of interdependent ITU Recommendations (among others M.687 [159], M.1645 [160], M.1457 [149]). IMT-2000 provides a framework for worldwide wireless access by linking the diverse systems of terrestrial and/or satellite based networks. It will exploit the potential synergy between digital mobile telecommunications technologies and systems for fixed and mobile wireless access systems. ITU activities on IMT-2000 comprise international standardization (including frequency spectrum and technical specifications for radio and network components, tariffs and billing, technical assistance and studies on regulatory and policy aspects).

It was within Study Group 8 (SG8) (with as scope: systems and networks for the mobile, radiodetermination and amateur services, including related satellite services) that IMT-2000 [149], [159], [160] was elaborated. *Working Party 8F* (WP 8F, scope: IMT-2000 and systems beyond IMT-2000) had the prime responsibility within SG8 for issues related to the terrestrial component of IMT-2000 and beyond, related to Question ITU-R 229-1/8: 'Future development of IMT-2000 and systems beyond IMT-2000'. WP 8F worked closely with WP 8D (scope: All mobile-satellite services and radiodetermination-satellite service) on issues related to the satellite component of IMT-2000 and beyond.

The five interfaces that were originally adopted in 2000 in Recommendation ITU-R *M.1457*, defining the 'Detailed specifications of the radio interfaces of International Mobile Telecommunications-2000 (IMT-2000)' are [149]:

- IMT-2000 CDMA Direct Spread
  based on UTRA FDD (Universal Terrestrial Radio Access Frequency Division Duplex) or WCDMA (Wideband Code Division Multiple Access) by 3GPP (3rd Generation Partnership Project)
- IMT-2000 CDMA Multi-Carrier
  based on cdma2000 (Code Division Multiple Access 2000) by 3GPP2 (3rd Generation Partnership Project 2)
- IMT-2000 CDMA TDD
  based on UTRA TDD (Universal Terrestrial Radio Access Time Division Duplex) by 3GPP
- IMT-2000 TDMA Single-Carrier
  based on UWC-136 (Universal Wireless Communication) by TIA/EIA (Telecommunications Industry Association/ Electronic Industries Alliance) and EDGE (Enhanced Data rates for Global Evolution) by 3GPP
- IMT-2000 FDMA/TDMA
  based on DECT (Digital Enhanced Cordless Telecommunications) by ETSI (European Telecommunications Standards Institute)

In 1992, during WARC-92, spectrum for IMT-2000 was allocated by the ITU-R in 1885-2025 MHz and 2110-2200 MHz. Additional bands were identified in 2000 during WRC-00: 806-960 MHz, 1710-1885 MHz and 2500-2690 MHz [161].

C. IEEE 802.16 and IMT-2000

In Nov. 2006, the IEEE contributed a proposal [162] to ITU-R WP 8F to add a new radio interface to IMT-2000. This interface was designated as *IP-OFDMA* and based on IEEE Std 802.16-2004 [65] and IEEE Std 802.16e-2005 [80] (see Section II-C). IP-OFDMA was derived from WiMAX Forum Mobile System Profile Release 1.0 Approved Specifications (Rev 1.2.2, 2006/11/17) [163] (see Section III-C). In Dec. 2006, the WiMAX Forum submitted a supporting contribution [164] to ITU-R WP 8F with additional technical details on IP-OFDMA (revised in Jan. 2007).

In Oct. 2007, the Radiocommunication Assembly (RA-07) approved this new interface in the seventh revision of Recommendation ITU-R M.1457, denoted as ITU-R *M.1457-7* [149]. However, the interface was renamed to *IMT-2000 OFDMA TDD WMAN*.

Following RA-07, the work on IMT, including both IMT-2000 and IMT-Advanced (see Section IV-E) collectively, is now being addressed under the new Study Group 5 umbrella by *Working Party 5D* (scope: IMT Systems) and SG8 is now disbanded. RA-07 revised the original study question into Question ITU-R 229-2/5 'Future development of the terrestrial component of IMT', to include both responsibility for the continued development and enhancement of IMT-2000 and the mandate to address all aspects of IMT-Advanced [165] (see Section IV-E).

In the next revision of M.1457 (i.e. M.1457-8) the OFDMA TDD WMAN was left unchanged. In M.1457-9 however, the interface is now based on IEEE Std 802.16-2009 [98] (see Section II-C) and WiMAX Forum Mobile System Profile Specification Release 1.5 [142](see Section III-D), which adds an FDD mode. In accordance with Circular Letter 8/LCCE/95 [166], ITU-R has historically updated Recommendation ITU-R M.1457 approximately annually using a three-meeting cycle.

D. Benefits of ITU recognition

One could question why the IEEE 802.16 WG would need to seek recognition from the ITU, as IEEE itself is an international standardization organization. However, the IEEE 802.16 WG understood the importance of ITU engagement right from the beginning. Their first PAR [26], initiating P802.16 (see Section II-C), already stated in 1999 that the resulting standard might be adopted eventually by the ITU and the WG appointed a ITU-R Liaison Official to maintain contacts with the ITU-R. IEEE 802.16 was mainly aimed at operating in licensed bands, typically used by telecommunications operators. As the traditional boundary between data communications and telecommunications was blurring, it was important for the IEEE 802.16 WG to have good contacts with the ITU because the telecommunication industry was always well represented there [12]. When IEEE became a Sector Member of the ITU-R in 2003, their relationship strengthened even further.

The ITU recognition offered indeed benefits that the IEEE could not have gained on its own, as the inclusion of WiMAX technology by ITU in 2007 in its IMT-2000 program (as OFDMA TDD WMAN, see Section IV-C) added international credibility to the technology. Mobile WiMAX technology now got the same level of recognition as UMTS/HSPA and CDMA2000/EV-DO, concerning worldwide reputation. Furthermore, one should not forget the impact of ITU on radio

[19]previously known as Future Public Land Mobile Telecommunications Systems (FPLMTS)

regulation. Certain radio frequencies (e.g. 2.5-2.69 GHz) are classified for use with IMT-2000 technologies only [11]. WiMAX's inclusion in IMT-2000 enables spectrum owners to use WiMAX equipment in any country that recognizes IMT-2000.

E. IMT-Advanced

In 2007, it was agreed upon in ITU-R Resolution 56 [167] that the term 'IMT-Advanced' be applied to those systems, system components, and related aspects that include new radio interface(s) that support the new capabilities of systems beyond IMT-2000 and new spectrum was allocated for IMT systems during WRC-07 in 698-862 MHz, 790-862 MHz, 2.3-2.4 GHz and 3.4-3.6 GHz (although not always on a global scale) [168].

The principles for the process of development of IMT-Advanced are stated in Resolution 57 [169] and members were invited to submit proposals for candidate *radio interface technologies (RIT)*[20] for the terrestrial components of the radio interface(s) for IMT-Advanced, conform Circular Letter 5/LCCE/2 [170].

This letter was issued on the 7th of Mar. 2008, as a result of Step 1 of the submission and evaluation process as described in IMT-ADV/2 [171]. In Step 2, the RIT proposals were composed and during Step 3, the ITU-R was open for reception of RIT proposals until Oct. 2009. Afterwards, the proposals have been evaluated and reviewed during Step 4, 5 and 6. The decision on which RITs to include in IMT-Advanced was taken in Step 7 in Oct. 2010. Writing the final RIT specifications has been done in Step 8. The time schedule, as included in IMT-ADV/2 [171], is shown in Fig. 12.

F. IEEE 802.16 and IMT-Advanced

Within the time frame for submitting RIT proposals, the IEEE, Japan (advised by its Association of Radio Industries and Businesses (ARIB)) and the Korean TTA (Telecommunications Technology Association) each submitted a proposal based on the WirelessMAN-Advanced interface that was at that time still being drafted in IEEE P802.16m (see Section II-C). They are therefore referred to by the ITU-R as *RIT Proponents*.

Both the ARIB and the TTA (or more precisely: the IMT-Advanced Subcommittee of the Advanced Wireless Communications Study Committee of the ARIB on the one hand and the IMT WiBro Project Group, PG 702, of the TTA on the other hand) are collaborating with IEEE for those RIT proposals [172]–[175]. All the aforementioned proposals are therefore based on the same IEEE 802.16m System Description Document (SDD) [176]. In ITU terminology, the IEEE is therefore known as a *GCS Proponent*. A GCS Proponent provides the GCS (Global Core Specification), which is the set of specifications that defines a RIT. The IEEE therefore submitted a *Form A* document [177] to ITU-R in Oct. 2010 [178] to officially state its intent to be a GCS Proponent. Also in ITU terminology, the ARIB, TTA and WiMAX Forum are *Transposing organizations*, which are authorized by the GCS Proponent to derive standards from the GCS.

The proposals were acknowledged by the ITU-R in documents IMT-ADV/4 [179], IMT-ADV/5 [180] and IMT-ADV/7 [181], respectively. The IEEE proposal was furthermore endorsed by the WiMAX Forum in ITU-R Contribution 5D/558 [182].

All proposals have been evaluated and reviewed during Step 4, 5 and 6, along with three other proposals (IMT-ADV/6, IMT-ADV/8 and IMT-ADV/9 [183]–[185]) that include LTE-Advanced [186] (Long Term Evolution Advanced) technology by 3GPP. Each of the six candidate technology submissions has individually completed the evaluation process successfully [187], [188]. In Step 7, the three proposals that are based on IEEE P802.16m were grouped together into the technology identified in ITU as 'WirelessMAN-Advanced' while the other three proposals were grouped into the technology 'LTE-Advanced' [187], [188]. Both 'WirelessMAN-Advanced' and 'LTE-Advanced' were accepted for inclusion in the standardization phase of IMT-Advanced [187], [188] during WP 5D meeting no. 9 on 13-20 Oct. 2010.

The appropriate Recommendation, currently still temporarily referred to as ITU-R M.[IMT.RSPEC] [189], is now being developed in Step 8, conform procedures in IMT-ADV/24 [190]. The IEEE has submitted its GCS at the end of Mar. 2011 [191], in order for WP 5D to preliminary agree on a draft for ITU-R M.[IMT.RSPEC] in its 10th meeting on 6-13 Apr. 2011. In Mar. 2011, the IEEE has also submitted the *Certification B* document [192] which identifies the authorized Transposing Organization(s) utilizing the GCS [190], which are TTA (Korea), ARIB (Japan) and the WiMAX Forum (which were the RIT Proponents for 'WirelessMAN-Advanced'). The 'WirelessMAN-Advanced Transposing Organizations' (WATO) will hold joint meetings to align their views.

It is foreseen that transpositions to the GCS will be submitted by Sep. 2011, as well as a *Certification C* document, which is the statement by the Transposing Organization(s) that they have complied with the intentions indicated in Certification B [190]. Final agreement on the IMT-Advanced radio interfaces is then expected to be given by WP 5D in Oct. 2011, by SG 5 in Nov. 2011 and finally by the ITU-R in Feb. 2012 in a Radiocommunication Assembly [193].

G. Fourth generation (4G)

When development of IMT-Advanced started in 2007 by WP 5D, only the term 'IMT-Advanced' was used for systems beyond IMT-2000, but the '4G' term was never mentioned [193]. In Oct. 2010, the ITU itself, where WP 5D belongs to (see Fig. 11), suggested [194] that IMT-Advanced was the ITU's name for 4G, thus only including WirelessMAN-Advanced and LTE-Advanced. However, mobile operators (especially in the USA) were already marketing their newly deployed wireless technologies, i.e. LTE and WiMAX, as '4G' in order to differentiate from their earlier '3G' technologies, most notably UMTS/HSPA and CDMA2000/EV-DO. In order to mitigate confusion and to better approach current marketing, ITU changed its view on 4G in Dec. 2010 [195] by stating

[20]SRIT is used to denote a set of RITs.

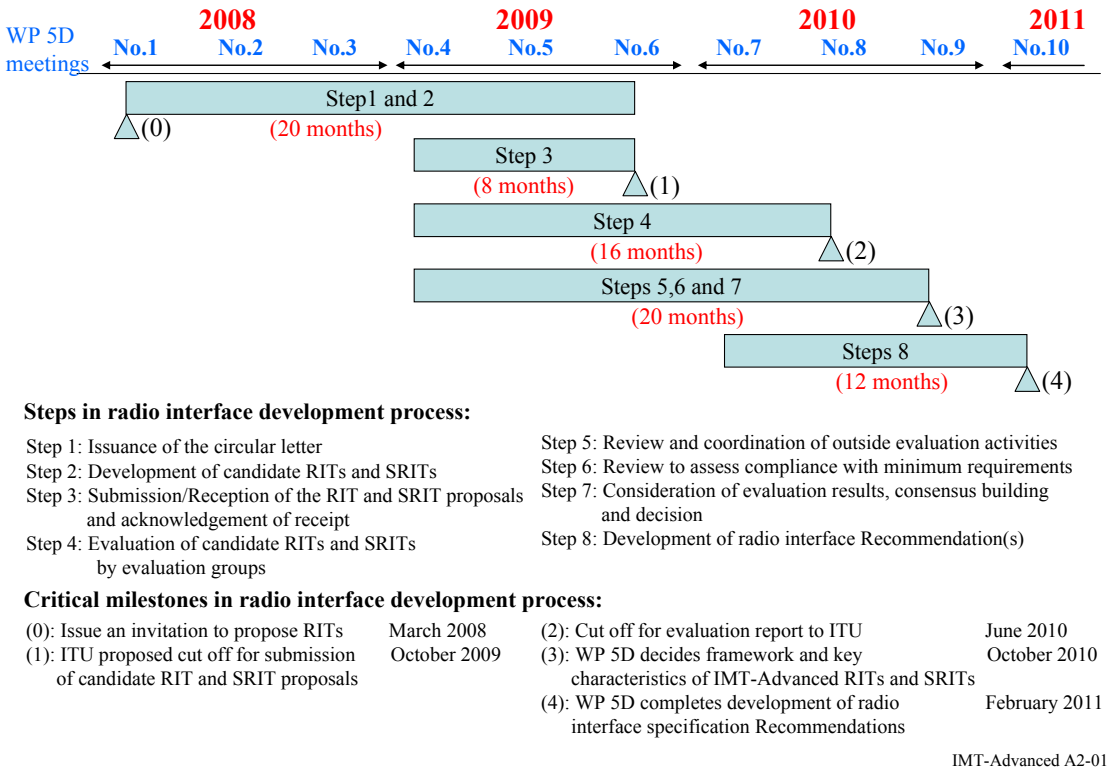

Fig. 12. Original time schedule for the development of IMT-Advanced radio interface recommendations [171]

that '4G' is actually an undefined term but applies to IMT-Advanced as well as 'to the forerunners of these technologies, LTE and WiMAX, and to other evolved 3G technologies providing a substantial level of improvement in performance and capabilities with respect to the initial third generation systems now deployed.' [195]

V. Trend Analysis

While standardization and certification efforts in multiple organizations, as described in the previous sections, is one thing, the real success of WiMAX can only be measured by the actual technology adoption in the field, as described within this section. A first indication of industry interest is given in Section V-A, where we analyze the attendance in IEEE 802.16 WG meetings where anyone is allowed to attend. Next, we look at the number of devices that have been WiMAX Forum Certified over time in Section V-B. Finally, we consider the number of WiMAX deployments worldwide in Section V-C.

A. IEEE 802.16 WG attendance

In Mar., Jul., and Nov. of each year, all the Working Groups of LMSC (see Section II-A), including the IEEE 802.16 WG, meet together in a plenary session [21]. Between two plenary sessions, the IEEE 802.16 WG also meets in an interim session in Jan., May and Sep. In Fig. 13 we plotted the IEEE 802.16 WG session attendance as this gives an indication of industry interest over time. We depicted attendance in plenary and interim sessions in separate series, as their difference does not reveal a difference in interest, but is due to practicalities (people visiting from other WGs during plenary sessions, attendance in some plenary sessions is required for membership, most plenary sessions are in the USA, etc.).

The first official session took place in Jul. 99 and attendance was steadily growing. The start of P802.16.3, where an air interface for frequencies below 10 GHz was being developed (see Table II), probably attracted new attendees in the beginning. At the 10th session, in Nov. 2000, a peak attendance of 211 people had been reached, but attendance decreased after its initial momentum.

We see a revival in attendance after the approval of IEEE Std 802.16-2004, showing that industry interest is growing. The ongoing work in P802.16e, where a standard was being developed to add mobility support (see Table III), especially received a lot of interest and IEEE 802.16 WG session attendance was high until session 38 (Jul. 05) where the LMSC EC granted conditional approval to forward the final draft of P802.16e to the IEEE-SASB.

Attendance decreased for the following sessions, but it increased once again when P802.16m was initiated and IMT-2000 OFDMA TDD WMAN (see Section IV-C) and IEEE Std 802.16-2009 (see Table IV) were being completed. The highest attendance so far (462 attendees), was on the 50th session in Jul. 2007. During this plenary session, for the first time, the 802.16 WG also had the highest attendance of all Working Groups at a LMSC plenary.

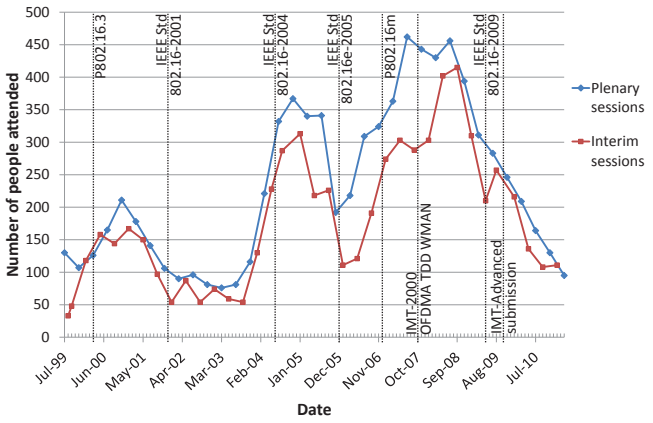

Fig. 13. Attendance at the IEEE 802.16 sessions.

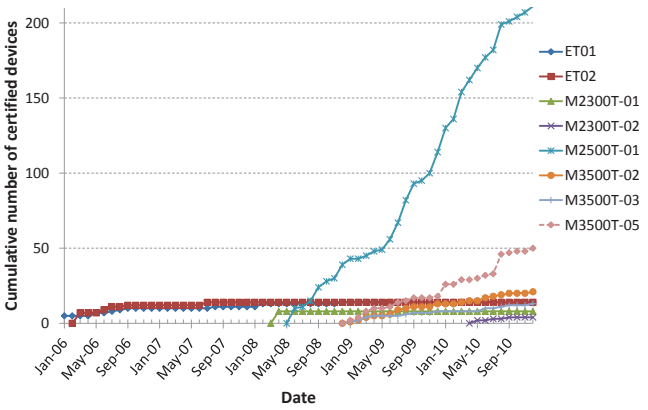

Fig. 14. Cumulative number of certified devices per certification profile

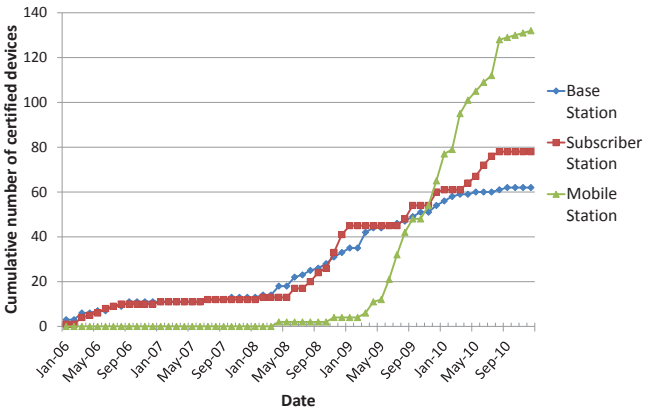

Fig. 15. Cumulative number of certified base stations, subscriber and mobile stations

As of end 2008, we see a quasi continuous decrease in session attendance, although interesting and important aspects are being dealt with, e.g. further development in P802.16m and IMT-Advanced submission (see Section IV-F). A possible explanation could be the fact that some major companies are ceasing WiMAX development (and only focus on LTE) to reduce costs in time of economic recession [196]. The future is yet to reveal whether industry interest will rise again.

B. WiMAX devices

Within this section, we collected and analyzed all specifications of the certified products that are listed in the WiMAX Forum Certified Product Registry[21](see Section III-E). In order to determine the supported certification profiles (see Section III-C) per device, we manually collected the data that is described on the official certificate of each certified device.[22]

The number of certified devices are cumulatively plotted over time per certification profile (see Section III-C) in Fig. 14, per device type in Fig. 15 and per WFDCL[23] (the certification lab, see Section III-E) in Fig. 16. A device type is either 'base station', 'subscriber station' or 'mobile station'. Note that, as a device can be certified for multiple certification profiles, the cumulative sum of the curves in Fig. 14 will be higher than the one in Fig. 15 or Fig. 16 where only unique devices are represented.

In Fig. 14 and Fig. 15 we can see that in Jan. 2006, the first base stations and subscriber devices operating in the 3.5 GHz band were certified, based on IEEE Std 802.16-2004 [65], under the Fixed WiMAX certification profiles (ET01 and ET02, see Table VIII). At that time, all certification was done in the AT4 Wireless lab in Spain, as shown in Fig. 16. Later, in Apr. 2008, the first Mobile WiMAX Certified products operating in the 2.3 GHz band and based on IEEE Std 802.16e-2005 [80] were announced (profile M2300T-01, formerly known as MP01, see Table IX), mainly targeted at the South Korean market for their WiBro (Wireless Broadband) service, offered over WiMAX. This marked the entrance of mobile stations into the market, as shown in Fig. 15, which growth would eventually largely exceed the one in (fixed or nomadic) subscriber stations. In Jun. 2008, The WiMAX Forum announced the first Mobile WiMAX Forum Certified devices operating at 2.5 GHz (profile M2500T-01, formerly known as MP05, see Table IX) [140]. This profile has ever since been included in many products and their number has grown fast as this frequency is allocated by the ITU for IMT-2000 technologies and as WiMAX has been included in IMT-2000 (see Section IV-C). The other WFDCLs also started certification around that time, as shown in Fig. 16. Bureau Veritas ADT in Taiwan particularly showed a strong growth in the number of certified devices. Several reasons could explain this observation. Firstly, many ICT manufacturers already produce products in Taiwan, so transportation cost is lower and relationships with the vendors are easy to maintain. Secondly, Bureau Veritas ADT is a private company which already tested products for other certification marks (e.g. CE, Wi-Fi, etc.). Thus, they already have good relationships with (the same) vendors for other product lines, have experienced sales teams and can offer competitive prices. This contrasts with e.g. TTC, also in Taiwan, which is a governmental organization with less experience and equipment. Bureau Veritas ADT might therefore be a more credible and attractive choice, compared to other certification labs. The cumulative number of certified

[21]The data was collected from the WiMAX Forum Certified Product Registry on 2 Jan. 2011

[22]We did not use the data as described in the product fiche on the WiMAX Forum website, as this was sometimes found to be inconsistent with the certificate itself.

[23]SIRIM QAS International is not included in the analysis as it was only selected as WFDCL in Apr. 2011 [197].

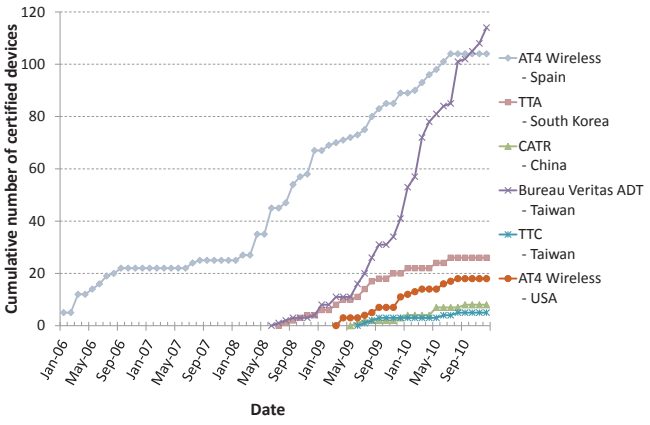

Fig. 16. Cumulative number of certified devices per WFDCL

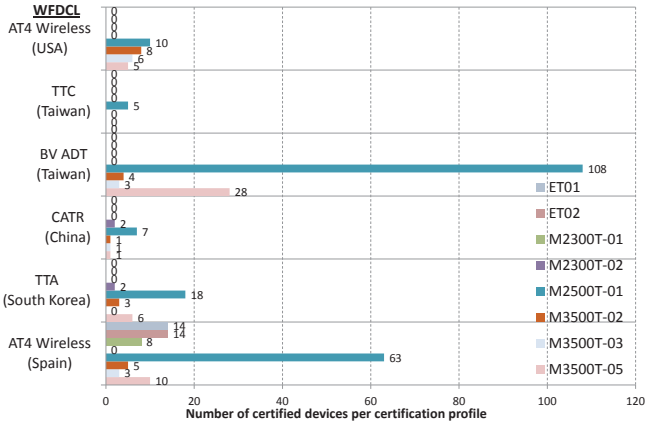

Fig. 17. Relation of the cumulative number of certified devices per certification profile and per WFDCL in Dec. 2010

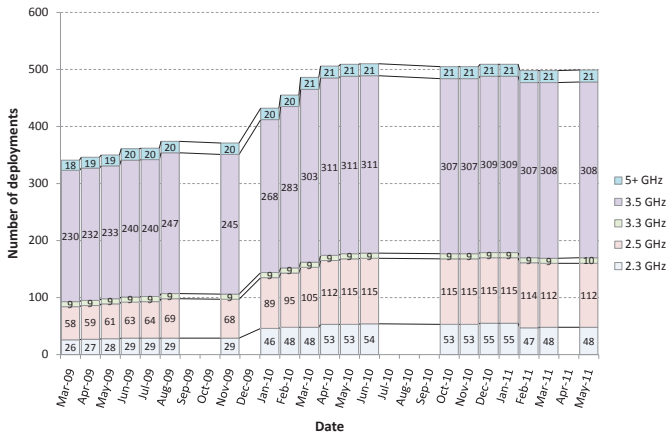

Fig. 18. Cumulative number of WiMAX deployments per frequency

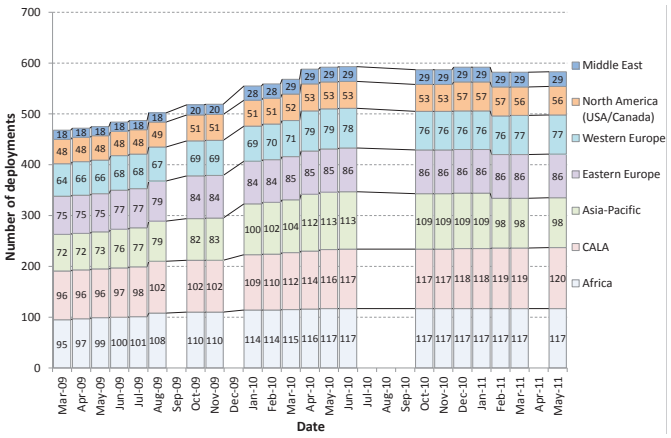

Fig. 19. Cumulative number of WiMAX deployments per geographic region

devices in Aug. 2010 is shown per certification profile per WFDCL in Fig. 17, which shows that every WFDCL has mainly focused on the M2500T-01 profile.

C. WiMAX deployments

We extracted and analyzed information about WiMAX deployments from all WiMAX Forum Monthly Industry Reports that appeared from Mar. 2009 till May 2011. We plotted the number of WiMAX deployments over time per frequency in Fig. 18 and per geographic region in Fig. 19.

Note that the WiMAX Forum uses the term 'deployments' to refer to WiMAX networks that are either in service, planned or in deployment (i.e. base stations that are being deployed, but there are few or no subscribers yet). Also note that the total number of deployments in Fig. 18 may not add up to the total number of deployments in Fig. 19, as the WiMAX Forum does not have all information for each deployment tracked. As there were no WiMAX Forum Monthly Industry Reports in Sep. 2009, Dec. 2009, Jul. 2010, Aug. 2010, Sep. 2010 and Apr. 2011, we could not present information for those months in Fig. 18 and Fig. 19. Furthermore, as the WiMAX Forum Monthly Industry Report of Oct. 2009 did not comprise information about deployments per frequency, this information is also missing in Fig. 18.

Most deployments are currently in the 3.5 GHz spectrum, but in Fig. 18 we see a strong growth over one year (from Mar. 09 till Mar. 10) of more than 80% in the number of deployments with a 2.3 GHz or 2.5 GHz frequency, compared to a 32% growth in the number of deployments in the 3.5 GHz. This corresponds with the observation of the explosive growth in certified devices for 2.5 GHz in Fig. 14. Although the number of certified devices is still growing, we see as of May 2010 a stagnation or even a small decrease in the number of deployments.

Fig. 19 shows that WiMAX is most often deployed in Africa, CALA (Caribbean and Latin America Region) and Asia-Pacific. There are lesser deployments in Eastern Europe, Western Europe, North America and the Middle East. In the early days of WiMAX, the technology was announced to be able to help in bridging the digital gap, based on its extended coverage over other wireless technologies at that time. Based on Fig. 19, most deployments do indeed seem to be happening in the geographical regions that are containing most of the developing countries.

However, as stated before, the figures include different types of deployments: both small and large and both preliminary and mature deployments. In order to know the actual potential per geographic region, we should rather look at the population coverage. This is an estimate that is yearly updated by the WiMAX Forum. The figures are included in the WiMAX Forum Monthly Industry Reports. We analyzed the figures of 2009, 2010 and 2011 and visualized them in Fig. 20.

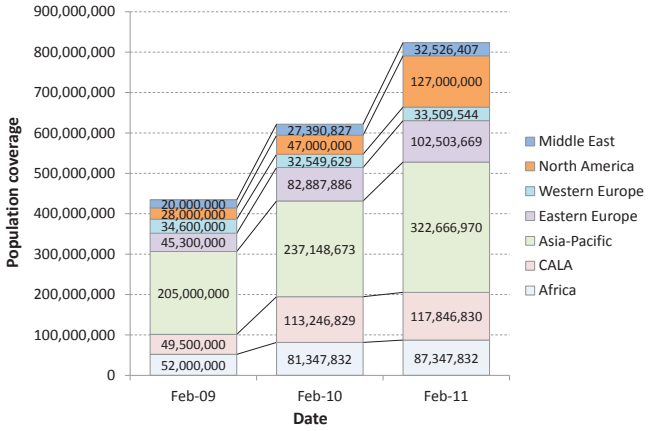

Fig. 20. Population coverage of WiMAX deployments per geographic region

Note that the numbers represent an estimate conducted by the WiMAX Forum via primary and secondary research on an operator-by-operator basis. Where the operator could not or would not respond to direct inquiry, estimates were made based on public operator statements, number of base stations, government-mandated buildout requirements, and other available information.

In Fig. 20 we see a different relation amongst the regions, compared to Fig. 19. The Asia-Pacific region is clearly the most 'WiMAX minded' region of the world, but the CALA and Africa also have quite an extensive uptake. People in regions containing the most developed countries do appear to have far lesser access to WiMAX technology. A possible explanation for this observation, might be the fact that, in those countries, most households already have broadband Internet at their homes via DSL or cable while cellular operators are offering mobile Internet access on the go. This contrasts with developing countries, where broadband Internet at home or on the go is often uncommon. As there are no incumbent competitors, new WiMAX deployments (known as 'green-field deployments') might therefore be much faster adopted. For further reference, note that the deployments are tracked by the WiMAX Forum and visualized on their website [198].

VI. Conclusion

Confucius already quoted 'Study the past if you would define the future'. We therefore did an in-depth investigation on the evolution of the different projects, working groups and standards within the IEEE 802.16 Working Group on Broadband Wireless Access, the WiMAX Forum and the ITU and considered their relationships.

Within the IEEE, the initial ideas about how to implement Broadband Wireless Access differ in many ways from the standards today. The focus of the IEEE 802.16 WG, the working group responsible for this topic, has shifted over time from 10-66 GHz spectrum to 2-11 GHz and other amendments were added for mobility, relaying, etc. Being open minded and including multiple physical layer options (WirelessMAN-SC, WirelessMAN-OFDM, WirelessMAN-OFDMA), while maintaining a single MAC protocol, led the IEEE 802.16 WG to where it is today. New features are still continuously being developed and added. The applicable standard today, May 2011, is IEEE Std 802.16-2009, amended by IEEE Std 802.16j-2009, IEEE Std 802.16h-2010 and IEEE Std 802.16m-2011. Further enhancements that are being developed concern higher reliability (P802.16n) and machine-to-machine communications (P802.16p).

The WiMAX Forum is the organization that derives system profiles, most notably Fixed WiMAX and Mobile WiMAX, and certification profiles out of the IEEE 802.16 standards and imposes additional network specifications. By certifying devices against WiMAX Forum requirements, one achieves interoperability among products of different vendors, global roaming, etc. The Mobile WiMAX profile is being further developed and has currently reached Release 1.5. A lot of preparations are being made by the WiMAX Forum to incorporate IEEE Std 802.16m-2011 into new Release 2.0 specifications.

Furthermore, the IEEE 802.16 WG maintained close contacts with the ITU, the radiocommunications division of the United Nations. Their collaboration eventually led to the inclusion of a new radio interface, IMT-2000 OFDMA TDD WMAN, into the IMT-2000 program of the ITU. This interface is based on IEEE Std 802.16-2009, together with the mobile system profile specifications Release 1.5 of the WiMAX Forum. The inclusion of WiMAX technology in IMT-2000 facilitates its deployment worldwide. In the new ITU program, IMT-Advanced, a proposal was submitted by the IEEE based on an early draft of IEEE Std 802.16m-2011 and WiMAX Forum's Release 2.0 preparations. This way IEEE 802.16 technology tries to keep up with competitive technologies like LTE-Advanced.

After analyzing the products that are currently WiMAX Forum certified and the different deployments over time, we found that most products today are being certified or deployed for the 2.5 GHz and 3.5 GHz frequencies. Furthermore, most deployments are currently in Asia Pacific, Africa and CALA with Asia Pacific having the largest population coverage. Today, May 2011, deployments appear to have somewhat stagnated, product certification rate is slightly reclining and session attendance is low. However, we have seen industry interest for WiMAX technology growing and shrinking in the past. In our opinion, everything has been undertaken by the respective standardization and certification organization to make the best out of WiMAX technology. Time will tell whether WiMAX will grow into a long standing technology in the future.

What we have learned from IEEE 802.16 and WiMAX anyhow, is that anyone developing a new standard, should not be blind to new elements which might drastically change the way forward, as one never knows how underlying techniques and industry interest might be evolving. Furthermore, the importance of certification should not be underestimated by anyone developing a new technology. For products to hit the market on a worldwide scale, interoperability between different vendors is a key issue for success. Finally, the collaboration with other international standardization organizations is not to be forgotten, as it could significantly rise the esteem the new technology is given and it could facilitate new deployments and development.

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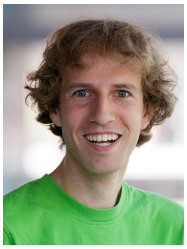

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