Broadband Wireless Access Networks – Standardization Activities in ETSI and other Fora

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Abstract: Broadband Wireless Access (BWA) is a topic of high-interest for Standard Development Organisations like ETSI and IEEE 802 as well as Industry Fora like WiMAX. Interoperable systems are progressed for fixed, nomadic and mobile users to cover different applications including broadband access, cellular backhauling and radio LANs.

This contribution addresses the ETSI activities in BWA systems and the relation to other organisations like IEEE 802.16 and the WiMAX Forum. ETSI Technical Committee BRAN is developing specifications for the lower layers of the air interface, network and management, testing of radio and protocols and is also active on regulatory matters including Harmonized European Norms and System Reference Documents to assist regulatory bodies in defining spectrum requirements and radio conformance specifications.

Keywords: Broadband Wireless Access (BWA), physical layer, MAC layer, ETSI BRAN, WiMAX Forum, IEEE 802.16, testing, certification, Harmonized European Norm (HEN).

1. OVERVIEW

The development of the air interface and complete network architecture for Broadband Wireless Access (BWA) systems has received high interest worldwide in the last decade. Intensive activities in terms of research, standardization, certification and promotion are continued in Standard Development Organisations (SDO) like ETSI, IEEE 802, ITU-R as well as Industry Fora like WiMAX Forum and WiFi Alliance. Specifications for interoperable systems and certification schemes are progressed for fixed, nomadic and mobile users to cover a bunch of different applications including broadband access, cellular backhauling and radio LANs.

Figure 1 shows an overview of the development of global wireless standards. SDOs like IEEE 802 and ETSI are depicted on left and right sides, resp. The horizontal ellipses indicate the scopes of Industry Fora a like WiMAX Forum for MAN (Metropolitan Area Networks) and WiFi Alliance for LAN systems.

This contribution addresses in particular the activities of ETSI Technical Committee BRAN (Broadband Radio Access Networks) in the field of wireless MAN systems and the relations to other organisations like IEEE 802.16 and the WiMAX Forum. The current key activities in ETSI BRAN include

- lower layer specifications (physical layer, MAC layer, convergence layer) for interoperable systems to enable communication over the air between equipment from different vendors;
- network and management specifications;
- conformance test specifications for radio and protocols;
- regulatory activities including Harmonized European Norms (HEN) and System Reference Documents (SRDoc) to assist regulatory bodies in defining spectrum requirements and radio conformance specifications.

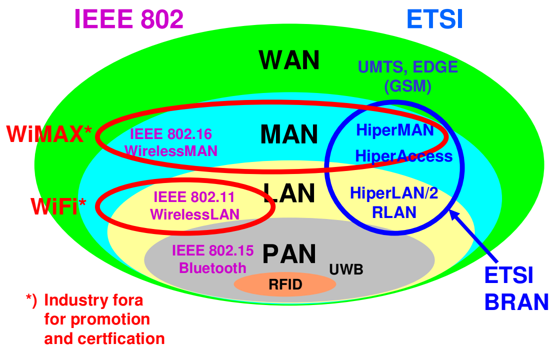

Fig. 1. Global wireless standards

2. TECHNOLOGY-SPECIFIC BWA STANDARDS

The BWA standards HiperMAN and HiperAccess were developed in ETSI BRAN and harmonized with IEEE 802.16. The closed activities on BRAN HiperLAN (similar to IEEE 802.11a) are not covered here.

2.1 System Architecture

Similar as for mobile radio, HiperMAN and HiperAccess are based on a Point-to-Multipoint (PMP) architecture (but also supporting point-to-point links and meshed networks) in a multi-cellular environment with a certain frequency-reuse factor. An example of a PMP system is shown in Figure 2, where HiperAccess is applied for UMTS backhauling.

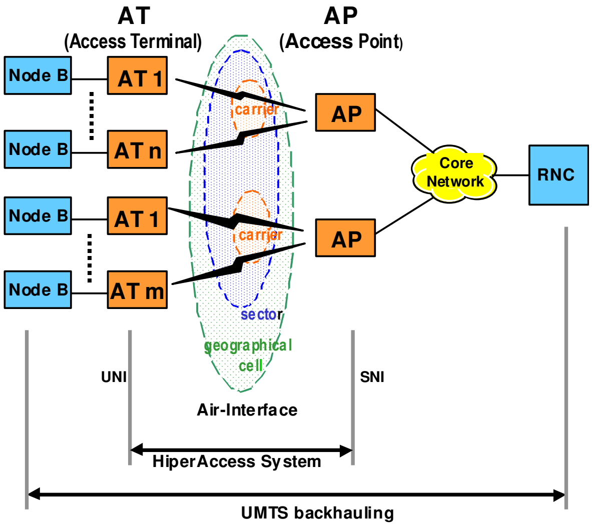

Fig. 2. Point-to-Multipoint (PMP) architecture

In a PMP system, a base station (called AP, Access Point) is connected to several terminals (called AT, Access Terminal). For each cell or each sector of a cell a different carrier frequency is used. Overlapping sectors are separated by different carriers (and perhaps by different polarizations).

The total data rate of up to 100 Mbit/s or more in a sector is efficiently shared among all terminals within a sector, with the possibility to allocate large parts of the total rate to a single terminal, typically on a short-term basis in case of traffic with variable data rate and high burstiness. This applies both for downlink (DL, from AP to AT) and uplink (UL, from AT to AP) directions.

2.2 Adaptive Operation and Packet-Based Transmission

The key idea for these systems is the combination of adaptive operation with packet-based transmission over the air interface.

The adaptive operation of the transmission scheme enables immediate reactions to changing propagation conditions. The combination of

- adaptive concatenated coding (with code rates from below ½ or up to 1) and
- adaptive modulation (between QPSK and 64-QAM)

provides a set of transmission schemes (addressed as PHY modes) ranging between very robust and very efficient modes, allowing to compensate a difference of 20 dB or more in terms of the required channel quality (see Section 4 for more details). This is supported by the application of

- adaptive transmit power control (ATPC) for both directions.

Adaptive coding, adaptive modulation and ATPC are selected and optimized individually per network element, and also individually per direction. Basically, the adaptive operation can be performed on a per cell or packet basis, supported by a control loop (including measurements, decisions and commands) with very fast operation in the order of few milliseconds, allowing immediate reactions to changing conditions and requirements.

The radio channel is characterized by time-variant quality, where slow changes are mainly caused by rain fading (typical for higher frequencies) and fast changes by burst-type co-channel and adjacent channel interference (from other AP or AT). Trade-offs are possible between range, throughput per sector or per network, quality and delay. At almost all times (defined by the availability, typically between 99.9% and 99.999%) very high data rates are guaranteed and reductions are only necessary during remaining short times when strong channel degradations occur.

Adaptive changes of the throughput are supported by adaptive operation of the scheduling mechanism, either centralized in the AP for PMP or distributed for other architectures. Provisioning of individual throughput per connection matches the individual QoS requirements of the connection.

From a more general point of view, cross-layer optimized systems offer considerable advantages over more traditional systems where the air interface is designed (and operated) independently from the service requirements. An essential benefit is also the multiplex gain since PMP systems can be considered as virtual multiplexers, operating as static or dynamic traffic concentrators, see Friedrichs (2004) for a detailed analysis.

2.3 HiperMAN Standard

The HiperMAN standards are developed in close cooperation with IEEE 802.16 and are optimized for frequencies below 10 GHz for non-LOS (Line Of Sight) conditions and channel bandwidths of 20 MHz or below. The main specifications are contained in ETSI documents

- TS 102 177 Physical layer
- TS 102 178 Data link control (DLC) layer

The variant HiperMAN1.2.1 or IEEE 802.16-2004 (see Eklund et al., 2002) is optimized for fixed access and the support of IP traffic, mainly intended for wireless-DSL type applications. It is based on OFDM modulation. The HiperMAN1.3.1 version is harmonized with IEEE 802.16e-2005 and based on SOFDMA (Scalable Orthogonal Frequency Division Multiple Access) for both directions, where the FFT size is between 128 and 2048 subcarriers. This implies that only some subcarriers can be used for a terminal (down to 1/16), resulting in a mix of TDMA and FDMA operation for capacity sharing and also allowing a transmit power reduction by 12 dB or a corresponding range extension. This results in extended degrees of freedom for interference-free operation. The term scalable means that the FFT size is proportional to the bandwidth between 1.25 and 20 MHz, so the symbol duration is always constant (to maintain a stable compromise between resistance against frequency-selective fading and phase noise). Additional options for error-control coding include cyclic and block Turbo codes, low density parity-check (LDPC) codes, space-time coding, MIMO and hybrid ARQ.

2.4 HiperAccess Standard

The HiperAccess standard is very similar to the SC-variant in IEEE 802.16-2004. The main specifications are contained in the following ETSI documents.

- TS 101 199 Physical layer
- TS 102 000 Data link control (DLC) layer
- TS 102 115 Convergence layer (CL) for cell-based transmission
- TS 102 117 Convergence layer (CL) for packet-based transmission

HiperAccess is optimized for frequencies above 11 GHz (for instance covering allocations in the 26, 28, 32 or 42 GHz bands or other frequency ranges), for a bandwidth of 28 MHz and distances of several kilometres under LOS conditions, see Friedrichs and Fazel (2000) and Fazel et al. (2002). It is based on single-carrier transmission, and an important goal for adaptive operation is also the overall minimization of co-channel interference to neighbour cells, supported by dedicated power control mechanisms per direction and the adaptive control of spectral efficiency in a wide range (see Section 4). This type of cellular BWA system is mainly limited by co-channel interference, whereas multipath propagation resulting in frequency-selective fading causes only minor degradations. The standard specifies the protocol mechanisms required for the robust operation of adaptive coding and modulation and adaptive transmit power in great detail, however the algorithms and various thresholds for these control loops have to be designed by the vendor of the network device.

Figure 3 shows the DL and UL frame structure for FDD operation of HiperAccess. For both directions frames of 1 ms duration with a certain frame offset are applied. The DL frame starts with a frame preamble for synchronisation, followed by a control zone for command purposes and the TDM zone as main part consisting of up to four PHY mode regions, where a PHY mode is defined as the combination of coding and modulation scheme (see Section 4 for details). From region 1 to 4, the robustness decreases and the efficiency increases. A PHY mode region consists of several code blocks where each code block carries up to four data packets (or ATM cells) as shown in Figure 4.

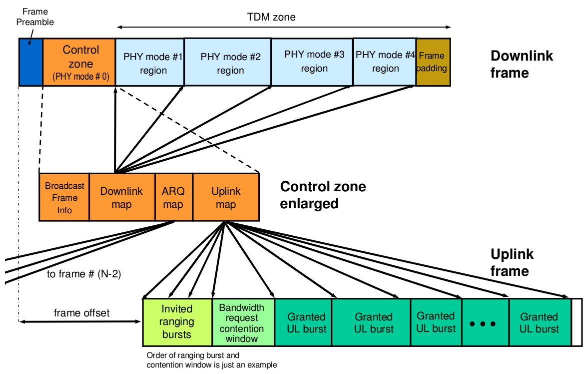

Fig. 3. Frame structure overview

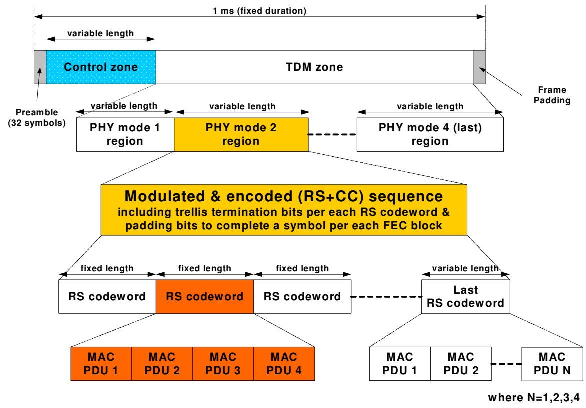

Fig. 4. DL frame structure and concatenated coding

Typically, an AT close to the AP can receive all PHY mode regions and will be addressed in region 4, whereas an AT at the border of the sector can typically receive only region 1 and will loose synchronisation after region 1. Of course, all packets are equipped with identities so that the AT can identify those packets addressed to this AT. The DL map of the control zone indicates the symbol numbers where the regions start. The UL map contains pairs of AT identities and symbol numbers in order to grant UL transmit opportunities to individual terminals. The ARQ map supports repetition strategies which are not explained here in detail.

The main application is cellular and hot-spot backhauling, see Friedrichs (2005). In contrast to its name, HiperAccess should be addressed as metro network or second-mile solution and not to be confused with the old ideas behind LMDS (Local Multipoint Distribution System), which got some prominence in the US around the year of 2000.

2.5 Duplex Scheme

Both HiperMAN and HiperAccess systems can operate in FDD (paired bands) and TDD (unpaired bands) frequency allocations and support also H-FDD terminals (paired bands but no simultaneous transmission and reception per terminal). These systems make very efficient use of the spectrum both for few as well as for several hundred terminals within a sector. The protocols are designed for high robustness whilst only adding a minimum of signalling overhead to the air interface.

Both systems can also be used for rural area purposes with long distances and few terminals, see Friedrichs (2003) for HiperAccess and Friedrichs and Goldhamer for HiperMAN (2006).

The advantage of FDD is that terminals regardless of their geographical position cannot cause interference to the base station in the UL. For TDD it is claimed very often that this offers more flexibility with regards to different throughput requirements per direction. However, if co-channel interference needs to be avoided in a multi-cellular environment, then TDD needs synchronisation between base stations, resulting in a more or less fixed split between DL and UL capacities, hence throughput flexibility per direction is reduced to a minimum as for FDD.

3. FIXED AND NOMADIC OPERATION

In a fixed network, all network elements are fixed in their positions, allowing for directional antennas as well as dedicated site and frequency planning. However, a feature like handover is even useful for networks with fixed terminals, in order to allow for load balancing supposed that an operator can use several carriers in the same sector. Nomadic operation means that transmission is switched off during movements of the terminal device, see Figure 5 for definitions. From the perspective of interference sensitivity from and to other systems in same or adjacent frequency bands and geographical locations, nomadic use is identical to mobile operation. Full mobility is characterized by fast and seamless handover and robustness of the air interface against propagation channel changes relative to the maximum supported speed. In case of handover, several base stations are involved under appropriate control of the access network. Especially the mechanism for soft handover imposes severe challenges to the access network.

Definition	Devices	Locations/ Speed	Handoffs
Fixed access	Outdoor and indoor CPEs	Single/ Stationary	No
Nomadic access	Indoor CPEs, PCMCIA cards	Multiple/ Stationary	No
Portability	Laptop PCMCIA or mini cards	Multiple/ Walking speed	Hard handoffs
Simple mobility	Laptop PCMCIA or mini cards, PDAs or smartphones	Multiple/ Low vehicular speed	Hard handoffs
Full mobility	Laptop PCMCIA or mini cards, PDAs or smartphones	Multiple/ High vehicular speed	Soft handoffs

Fig. 5. Definitions
(Source: WiMAX Forum White Paper, Nov. 2005)

In a PMP architecture, typically the base station is the master for the entire sector and the terminals act as slaves by reporting propagation conditions and bandwidth demands and vice versa following commands on when and how and what to transmit. In PTP (Point-To-Point) scenarios with a peer-to-peer relation between two devices, the transmitter acts as master and the receiver as slave resulting in direction-specific operation. Basically, the PMP architecture is also used for cellular radio (like GSM or UMTS) and RLANs (Radio LAN). Especially for RLANs also direct mode peer-to-peer communication is possible, either without any base station or under control of a base station.

The standardisation of interoperable systems needs to ensure that communication is possible between equipment from different vendors. This is obviously mandatory for nomadic use but offers also benefits to manufacturers and operators in case of fixed networks. However, the standards must be flexible enough to enable differentiated network elements (or even complete networks) from different manufacturers in order to initiate competition not only in costs but also on the level of vendor- or operator-specific features (like network management, configuration, planning, topology-agnostic solutions, etc.).

4. DATA RATES

The definition and calculation of data rates and throughputs in packet-based adaptive PTP and PMP systems is a separate and non-trivial matter. The capacity of a sector is the sum of the capacity of the individual links. The capacity of a link can change over time, where slow variations are caused by degradations of the propagation channel and fast variations are caused by traffic demands and service types of the terminal under consideration as well as those of all other terminals in the sector. All this is different for downlink and uplink directions. The capacity depends also very much on the distance between terminal and base station, hence the sector capacity depends on the distribution of the terminals within a sector. In case of traffic with committed data rates, other factors like required availability and local rain zone need to be taken into account as well.

The capacity from the user perspective is smaller than the air interface capacity due to error control coding, overhead required for the frame and packet structures, for terminal-specific exchange of data link control protocols and for broadcast channels in the downlink. Vice versa, the user capacity can be slightly increased by header compression in case of ATM. Considering error-control coding in more detail, high rates (small additional redundancy) could lead to the impression of an excellent ratio of user-to-gross bit rates. However, the opposite is true since low rates (large additional redundancy) increase robustness and therefore the throughput.

The basic calculation for HiperAccess throughput capabilities under ideal conditions is quite simple. For the concatenated coding scheme with outer Reed-Solomon code and inner convolutional code as shown in Figure 6, the spectral efficiency is calculated for a roll-off factor of 0.25 and different PHY modes corresponding to the PHY mode regions as introduced with Figures 3 and 4.

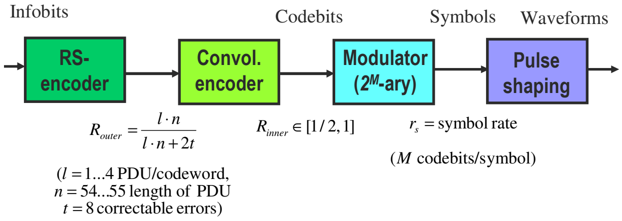

Fig. 6. Concatenated coding

For several PHY modes, ranging from very robust ones used for the control zone of the DL frame up to the most efficient ones, Figure 7 shows the relation between the spectral efficiency and the required carrier-to-noise plus interference ratio. The span of *C/(N+I)* is about 20 dB, and the spectral effciency varies in a considerable range between 0.52 and 4.46 bit/s/Hz. However, the calculation of the average realistic throughput is a far more complex topic.

PHY Mode	R_{outer} (for l=4)	R_{inner}	M	Spectral efficiency	$C/(N+I)_{required}$
0 (CZ)	0.65	1/2	2	0.52	6 dB
1 (all sets)	0.93	2/3	2	0.99	8 dB
2 (all sets)	0.93	1	2	1.49	12 dB
3 (set 1)	0.93	7/8	4	2.60	18 dB
4 (set 1)	0.93	5/6	6	3.72	24 dB
3 (set 2)	0.93	1	4	2.98	20 dB
4 (set 2)	0.93	1	6	4.46	26 dB

Fig. 7. Relation between spectral efficiency and required *C/(N+I)* for different PHY modes

In order to achieve a classification of realistic throughputs, ETSI BRAN contributed to the concept of RIC (Radio Interface Capacity) developed by ETSI TM TM4 in Technical Report TR-4147. Additionally, the BRAN HiperAccess standard is also covered in the generic harmonized standard EN 301 753 for multipoint digital fixed radio systems developed by TM4.

5. TESTING

An important activity within ETSI BRAN is the development of specifications for the testing of protocols and microwave aspects. Technical specifications for

- PICS (Protocol Implementation Conformance Statement),
- TSS&TP (Test Suite Structure and Test Purposes),
- ATS (Abstract Test Suite) and
- RCT (Radio Conformance Test)

are typically normative parts of the standards. The following ETSI documents contain the test specifications for HiperAccess

- TS 102 123 HiperAccess RCT
- TS 102 149-1/2/3 HiperAccess DLC
- TS 102 147-1/2/3 HiperAccess cell-CL
- TS 102 148-1/2/3 HiperAccess packet-CL

and for HiperMAN

- TS 102 385-1/2/3 HiperMAN1.2.1 DLC
- TS 102 545-1/2/3 HiperMAN1.3.1 DLC

According to a co-operation agreement between ETSI and the WiMAX Forum signed in 2005, BRAN is guiding Special Task Forces (STF, based on shared funding) where experts are developing the protocol conformance test specifications listed above. For instance, about 3000 separate test cases have been developed and validated for HiperMAN DLC testing. These are used for the certification of WiMAX compliant devices to assure interoperability, however it should be noted that the certification scheme itself including test case priorities and all other technical, operational and legal aspects of the certification process are under full control of the Industry forum.

Generally, in order to maximize the best probability of interoperability between products from different vendors, conformance testing and interoperability testing need to complement each other, both methods are compared in Figure 8. The experience has also shown that even without the requirement of interoperability, the careful and tedious development of protocol conformance test specifications provides essential guidance to correct errors and inconsistencies in the base standards. Even more important, the development of test specifications provides the basis for the validation of the fundamentals and details of the design concept. Potential problems can be detected and resolved before the hardware implementation becomes available.

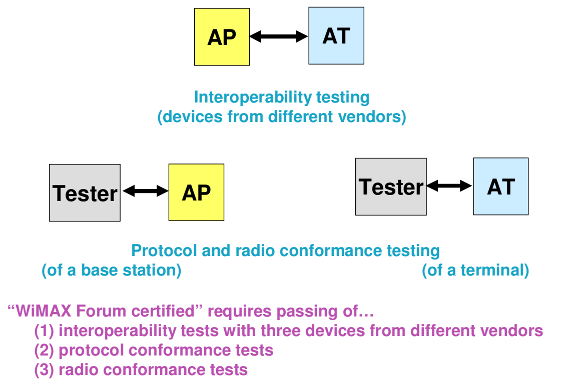

Fig. 8. Interoperability versus conformance testing

Figure 9 shows the process for conformance testing according to the ISO 9646 scheme. It is important to emphasize that a continuous interaction between all involved partners is essential, in the case of HiperMAN this includes

- ETSI Technical Committee BRAN
- WiMAX Forum
- ETSI PTCC (Protocol and Testing Competence Centre)
- ETSI STF (Special Task Force), a group of experts, funded by ETSI and the WiMAX Forum, operating under the guidance of ETSI BRAN
- Test houses, e.g. AT4Wireless in Malaga, Spain
- Test tool vendors
- Manufacturers

The coordination of this process is one of the major tasks for ETSI BRAN and the associated STFs.

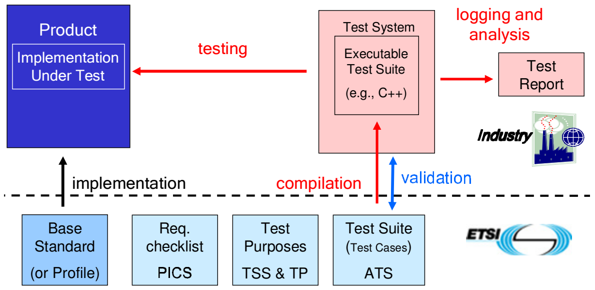

Fig. 9. Conformance testing scheme

In case of HiperMAN, the testing for WiMAX conformance is continuously leading to a series of corrigenda versions of the IEEE 802.16 standard. This is a nice example of fruitful cooperation and harmonization between the three organizations ETSI BRAN, IEEE 802.16 and the WiMAX Forum.

In case of HiperAccess, good results were achieved from using advanced specification languages such as ASN1, MSC, SDL and TTCN3 for the description of the normative and exceptional behaviour. In particular the specification of an API (Application Programming Interface) for UDP/IP based testing of protocol prototypes enables faster and less expensive validation of test suites due to protocol testing and debugging over the test network rather then over the expensive radio layer.

Just recently, discussions were started (but nothing has been agreed so far) to extend the co-operation with the WiMAX Forum towards NWIOT (Network Interoperability Testing) in order to ensure also interoperability in the access network. It is expected that key aspects include handover, network entry and selection, registration and location, service flow management, etc., however the core network and the IMS architecture will not be touched. Since IEEE 802.16 standardization activities do not cover networking, the WiMAX Forum needs to address these issues to establish global roaming and handover for mobile WiMAX terminals. However, at the time being it is still an open issue if ETSI will be involved in the development of another mobile radio standard complementing (or competing to) 3GPP/UMTS.

6. HARMONIZED STANDARDS

Any Harmonized European Norm (HEN) shall cover the essential requirements of article 3.2 of the R&TTE (Radio and Telecommunications Terminal Equipment) Directive 1999/5/EC, i.e., radio equipment shall be so constructed that it

- effectively uses the allocated spectrum and
- avoids harmful interference, in particular to other systems and technologies operating in the same or adjacent bands.

In addition to the requirements of a HEN, the interference-free co-existence between technologies must also be supported by a combination of spectrum engineering, equipment engineering, physical or geographical isolation and the appropriate license regimes under national responsibility.

For the cooperation with CEPT ECC, typically ETSI prepares SRDocs (System Reference Documents) for a better understanding of spectrum requirements and co-existence issues and to enable compatibility studies between different technologies (also with ITU-R).

BRAN is currently active on the following HENs:

- EN 301 893 on RLANs in the 5 GHz range (including TR 102 439 template for test report), also addressing high throughput technologies like channel bonding and MIMO (as developed by IEEE 802.11n).
- EN 302 502 on fixed wireless access in the 5.8 GHz range. This band as well as the 5 GHz band is unlicensed and pioneering work on DFS (Dynamic Frequency Selection) has been carried out in ETSI BRAN. Mechanisms have to be applied to secure the operation of primary users like military radars in this band.
- EN 302 544 draft on Broadband Data Transmitting System equipment operating in the frequency range 2500-2690 MHz. This is the UMTS extension band and interference-free operation between WCDMA and WiMAX equipment is considered as a very essential requirement. The amount of technology-neutrality in this HEN is still under discussion, also considering draft advice from the European Commission on more flexible use of the radio spectrum. Investigations are ongoing in ITU-R WP8F and CEPT ECC PT1 on compatibility studies between WiMAX TDD (and FDD) systems and WCDMA FDD systems. Since the base station is subject to national regulation the focus is currently on sharing studies for the UL.

BRAN is currently active on the following SRDocs:

- TR 102 555 on Personal Areas Networks in the 60 GHz range for Gbit/s applications.
- TR 102 453 Parts 1 and 2 on converged fixed-nomadic BWA systems above 3.4 GHz / below 3.4 GHz.

7. SOFTWARE DEFINED RADIOS (SDR) AND COGNITIVE RADIOS (CR)

ETSI BRAN is considering possibilities to overcome spectrum limitations by applying SDR and CR technology. However, there is no common view on the need for standardization in this field as indicated by a workshop recently organized by ETSI (Feb. 2007).

With the view of SDR as an implementation issue to effectively realize multi-standard terminals, there is no impact on the transmitter and thus no need for standardization. A standardization of separate modules or interfaces between modules would even hamper the technical development. The costs of mobile terminals are determined by RF requirements (like masks, linearity, spurious emissions) where SDR does not promise any cost reductions.

In contrast, end-to-end re-configurability means that the selection of best access technology and the hand-over is controlled by the network, where the amount of flexibility on the system level can range from dynamic adaptation of the lower layers by parameters to different radio access technologies or standards.

For wide area applications (characterized by cell planning, coordinated spectrum usage, high performance RF) the guarantee of clean spectrum without any interference is essential to maximize throughput. It is unclear if interference-free spectrum sharing to support spectrum trading will be acceptable. In contrast, for local area applications (no cell planning, uncoordinated spectrum usage, short term ad-hoc spectrum use, low performance transceivers), standardization of SDR and CR could be useful.

8. SUMMARY OF RELATIONS

The triangle relation between the key players shown in Figure 10 is supported by formal co-operation agreements. The co-operation with IEEE shows how standard bodies can successfully contribute to each other. Regarding the co-operation between ETSI and the WiMAX Forum, ETSI benefits from WiMAX marketing and certification, whereas the WiMAX Forum benefits from ETSI experience and work approach. Due to the different focus of the three organizations there is no wide overlapping but good completions. The relation to spectrum regulatory bodies like CEPT ECC is also essential to secure the necessary bandwidth for all types of BWA systems.

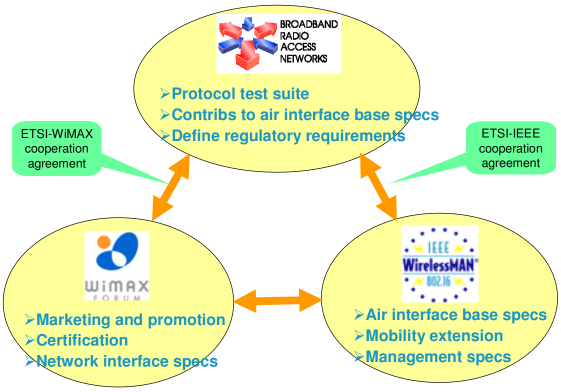

Fig. 10. Focus and relations between key players

9. CONCLUSIONS

SDOs like ETSI and are key drivers in the development of BWA systems matching market requirements in terms of costs, quality, flexibility, etc. The development of technology-specific BWA standards need to be complemented by regulatory activities to provide guidance for efficient spectrum regulations.

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BIOGRAPHY

Bernd Friedrichs graduated in mathematics and computer science from the Technical University of Braunschweig, Germany, in 1980. He received the Ph.D. degree in electrical engineering from the University of Erlangen in 1990. He was appointed Honorary Professor at the University of Karlsruhe in 2002. Since 1980 he has been with AEG-Telefunken, ANT Telecommunications, Bosch Telecom, Marconi Communications and now Telefon AB LM Ericsson, Germany, working on digital signal processing, coding and cryptography, mobile radio, protocol testing and system design of wireless access systems. He is also a lecturer at the University of Karlsruhe and has authored a textbook on information and coding theory. He has chaired TC BRAN since end of 2002 and has participated in TC BRAN activity since 1998.