The Data Link Control (DLC) Layer of the ETSI BRAN HiperAccess Standard

Bernd Friedrichs[1], Massimiliano Buscato[2], Giulio Cavalli[3], Per Emanuelsson[4], Juha Salokannel[5], Ken Stanwood[6], Stefan Wahl[7], Milan Zoric[8]

[1] *Marconi Communications GmbH, Backnang, Germany, Bernd.Friedrichs@marconi.com*
[2] *Ericsson, Milano, Italy, Massimiliano.Buscato@eri.ericsson.se*
[3] *Siemens, Milano, Italy, Giulio.Cavalli@icn.siemens.it*
[4] *Telia Research, Malmö, Sweden, Per.J.Emanuelsson@telia.se*
[5] *Nokia Research Center, Tampere, Finland, Juha.Salokannel@nokia.com*
[6] *Ensemble Communications, San Diego (CA), ken@ensemble.com*
[7] *Alcatel, Stuttgart, Germany, Stefan.Wahl@alcatel.de*
[8] *ETSI, Sophia Antipolis, France, Milan.Zoric@etsi.fr*

Abstract: The ETSI BRAN HiperAccess standard defines an interoperable Point-to-MultiPoint system for broadband fixed wireless access. Technical Specifications have recently been approved for physical and Data Link Control (DLC). The main features of the DLC layer include the frame structure, request-grant mechanisms, connection management, terminal initialization, radio resource control, security, and protocol primitives together with their transport mechanism. Fast adaptive modulation and coding is supported to cope with time-variant rain-fading and co-channel interference. Fast re-allocations of spectrum in reaction to variable-rate data services provide high statistical multiplex gains. Due to the high availability of the radio link, HiperAccess systems are perfectly suitable for UMTS backhaul and other broadband access applications.

Keywords: Broadband Wireless Access (BWA), Point-to-MultiPoint (PMP), Time Division Multiple Access (TDMA), UMTS backhaul, DLC layer, ASN.1, SDL, MSC, Testing.

1. INTRODUCTION

The ETSI BRAN (Broadband Radio Access Networks) HiperAccess (HA, High Performance Access) standard is a specification for the air interface of fixed broadband wireless access systems providing an interoperable Point-to-MultiPoint (PMP) architecture. The terms BWA or FWA are also widely used for such systems and general introductions can be found in Decanis (2002) or ETSI TR 102003 (2002).

The Technical Specification (TS) of the physical (PHY) layer (see ETSI TS 101999, 2002) and DLC layer (see ETSI TS 101200, 2002) for HA systems were approved by ETSI in February and April 2002, respectively, and other TSs for convergence layers (CL) as well as normative conformance test specifications will be published by October 2002.

The PHY and DLC layers are independent of the core network. In order to guarantee interoperability between Access Point (AP) and Access Terminal (AT) equipment developed by different manufacturers, all features of the HA DLC layer (including exceptional behaviour) are specified in detail, especially frame structures and request-grant mechanisms, all functions for connection management, terminal initialization, radio resource control and security as well as all protocol primitives and their transport mechanism.

Single-carrier transmission is used for downlink (DL, AP to AT) and uplink (UL, AT to AP) directions. TDM and TDMA (Time Division Multiple Access) schemes are employed for DL and UL, respectively. HA systems are designed for high spectral efficiency and flexibility, where adaptive operation is the key feature.

- Fast adaptive modulation and coding is supported for both link directions to cope with time-variant rain-fading and co-channel interference, guranteeing also a high availability of the radio system.
- Fast re-allocations of spectrum in reaction to variable-rate data services provide high statistical multiplex gains.

For the coverage of large areas, a cellular structure with a certain frequency re-use factor is required, and usually each cell is divided into sectors. For each sector and for each RF channel, a PMP system is operated individually, consisting of an AP (or APT, see Figure 1) and one or more ATs. HA systems are envisaged for frequency allocations above 11 GHz and RF carrier bandwidths of 28 MHz, where for the 32 and 42 GHz frequency blocks a large bandwidth of about 2 GHz is available in total. Both Frequency and Time Division Duplex (FDD and TDD) modes are supported for paired and unpaired frequency allocations, respectively.

The radio channel is characterized by rain fading with fast variations in the attenuation (up to 20 dB/s), intersymbol interferences (due to multipath propagation even for line-of-sight conditions) and co- or adjacent-channel interference that is typically time-invariant in DL (caused by other APs) but typically time-variant in UL (caused by the TDMA burst transmission mode from other ATs). In order to maximize spectral efficiency, the DLC layer must provide for DL and UL directions advanced mechanisms for individual link adaptation, i.e., fast adaptive PHY mode changes (including both adaptive coding and modulation) and adaptive power control, see ETSI TS 101999 (2002) for more details. Four or three PHY modes can be selected for DL and UL, respectively, under full control of the AP.

The HA standard was developed with the goal of meeting the requirements of a broad range of applications, including UMTS backhauling, SME, SOHO (Small Office Home Office), multi-dwelling and residential access, where data rates and service types can vary considerably between these different applications, see ETSI TR 102003 (2002). To deliver the appropriate data rate needed for the service chosen at any time, "bandwidth on demand" with data rates per AT of up to around 100 Mbit/s is supported efficiently by the standard.

Packet and cell-based CLs are defined for the transport of IP and ATM. The DLC and PHY layers are independent of the core network. At the DLC level four service categories have been defined (related to ATM classes CBR, VBR-rt, VBR-nrt, UBR):

1. Periodic realtime (PRT): fixed bandwidth guaranteed; tight constraints on both delay and delay variation.
2. Realtime (RT): minimum bandwidth guaranteed; tight constraints on both delay and delay variation.
3. Non-realtime (NRT): minimum bandwidth guaranteed; no constraints on delay or delay variation.
4. Best Effort (BE): no bandwidth guaranteed; no constraints on delay or delay variation.

The DLC layer provides efficient request-grant mechanisms to support these services types.

The general philosophy of the BRAN HA standard is to limit the number of optional features or principal options to a minimum, since this simplifies the implementation, enhances the robustness and is finally the key for true interoperability between devices produced by different vendors.

The paper is organized as follows. In Section 2 an overview on the HA system architecture is given. The main functions of the HA DLC layer according to ETSI TS 102000 (2002) are described in Section 3. Some performance results are reported in Section 4. The specification approach is covered shortly in Section 5. Conclusions are summarized in Section 6. An overview of the PHY layer is given in ETSI TS 101999 (2002) or Fazel (2002).

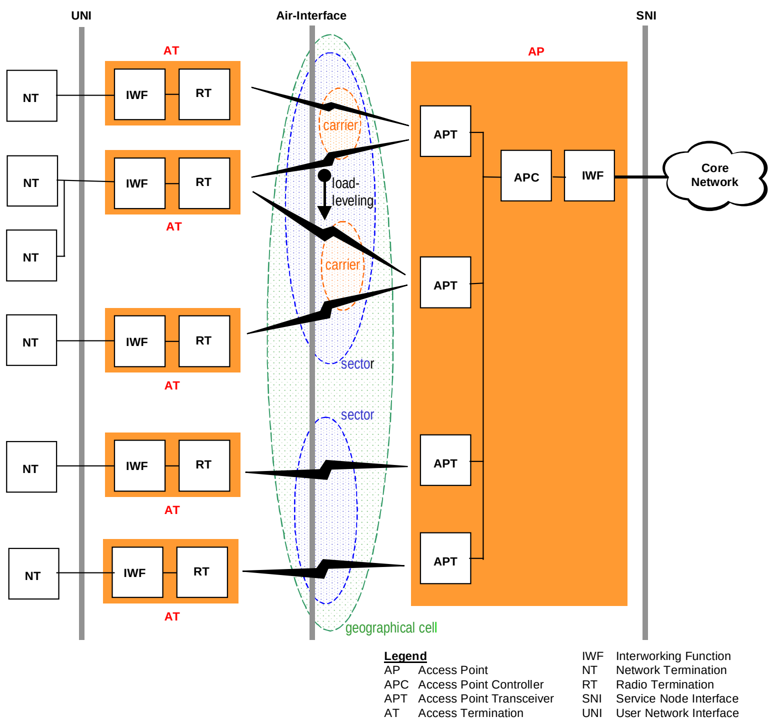

Figure 1: Configuration model for HiperAccess systems

2. SYSTEM ARCHITECTURE

A general overview of PMP systems with access schemes based on TDM/TDMA is given in Friedrichs (2000). The specific configuration model for HA systems is shown in Figure 1. The HA system will be deployed to connect user-network interface (UNI) physically fixed positioned in customer premises to a service node interface (SNI) of a broadband core network (e.g. IP, ATM, LL, etc.). The AP typically manages the communication of more than one sector. If there are several sectors per cell or several RF channels per sector, the AP can be split into an APC (Access Point Controller) and several APTs (Access Point Transceivers). An AT can be switched from one to another RF channel under control of the APC (load-leveling or inter-carrier handover), however, this is not a seamless procedure since a new initialization of the AT is required.

An overview of the HA protocol stack is shown in Figure 2. The stack consists of the core network-independent PHY and DLC layers and one or more CLs. The interfaces between DLC and PHY layers as well as between DLC layer and CL are only informative but not normative. The scope of the HA standard ends at the upper end of the CL. On top of the CL further higher layers are located.

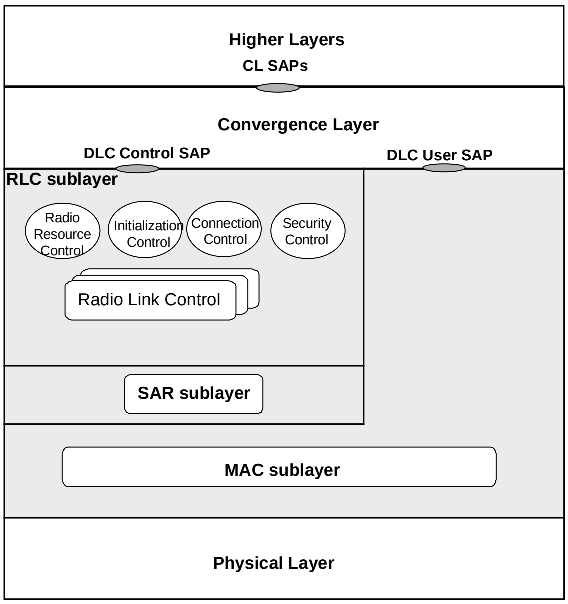

Figure 2: Layer structure (DLC layer shaded)

The Radio Link Control (RLC) sublayer contains all functions for radio resource control (load leveling, power control for UL and change of PHY modes for DL and UL), initialization control (first access to the network and re-access after longer link interruptions due to rain fading), connection control (setup, change and deletion of connections) and security control (encryption for privacy, authentication of ATs). Service primitives to the CL only exist for connection control, since all other functions are related to the AT and not to particular connections. The security functions are restricted to the DLC layer and are invisible for the CL.

The request-grant mechanism and the control of the frame structure are located in the Medium Access Control (MAC) sublayer. The Automatic Repeat Request (ARQ) mechanism is part of the MAC sublayer. The Protocol Data Units have a fixed payload size of 51 bytes on the DLC level (called MAC PDUs).

- Cell-based CL: There is a one-to-one correspondence between ATM cells and MAC PDUs. The ATM cell is shortened by 2 bytes from 53 to 51 bytes in the CL, since the HEC field is not needed due to very strong error detection capability of the Reed-Solomon codes and the VPI field is mapped on the Connection Identity field (CID, see Table 1).
- Packet-based CL: IP packets are segmented and mapped to the MAC PDUs via AAL5-ATM using the functions of the cell-based CL.

If MAC management messages generated in the DLC layer are longer than 51 bytes, then they are matched to the MAC PDUs by the Segmentation and Reassembly (SAR) sublayer.

The DLC layer is connection-oriented, this means that MAC PDUs are received in the same order as sent and that a connection is set up before MAC PDUs are sent to guarantee QoS. Connections are uni- or bi-directional. Broadcast connections and multicast connections exist only for the DL direction. Specific bidirectional management connections are set up at initialization for the transmission of protocol primitives (messages).

3. MAIN FEATURES OF THE DLC LAYER

3.1 MAC PDU Format

A MAC PDU consists of the payload with a fixed size of 51 bytes and the header with a size of 3 bytes for DL and 4 bytes for UL as shown in Table 1.

Table 1: MAC PDU header for DL and UL

Number of bits	Field description
Downlink	
3	PT = PduType
2	EKS = EncrKeySeq
16	CID = ConnId
1	IVP = IndVarPdu
2	Rsvd = reserved
Uplink	
3	PT = PduType
2	EKS = EncrKeySeq
16	CID = ConnId
8	PB = Piggyback
1	PM = poll-me
1	RSB = request for short UL burst (for MAC signaling PDU)
1	IVP = IndVarPdu

The addressing of MAC PDUs to/from ATs is done per CID. Data and signaling MAC PDUs are distinguished by the PT field. The EKS field is used for the encryption key replacement. The PB, PM and RSB fields in the UL header are described in Section 3.5.

3.2 Frame Structure

The DL and UL transmissions are structured in frames with a fixed length of 1 ms shown in Figures 3 and 4.

There is a fixed Frame Offset (FO) between DL and UL frames of at least 0.4ms for the FDD mode. In case of the TDD mode, the 1 ms frame is split into one DL subframe and one UL subframe.

The description below is restricted to FDD (however, the TDD structure is very similar). The AP is full-duplex FDD (i.e., all APs transmit and receive simultaneously), while the ATs can be either full-duplex or half-duplex (H-FDD AT, i.e., the AT can not transmit and receive simultaneously).

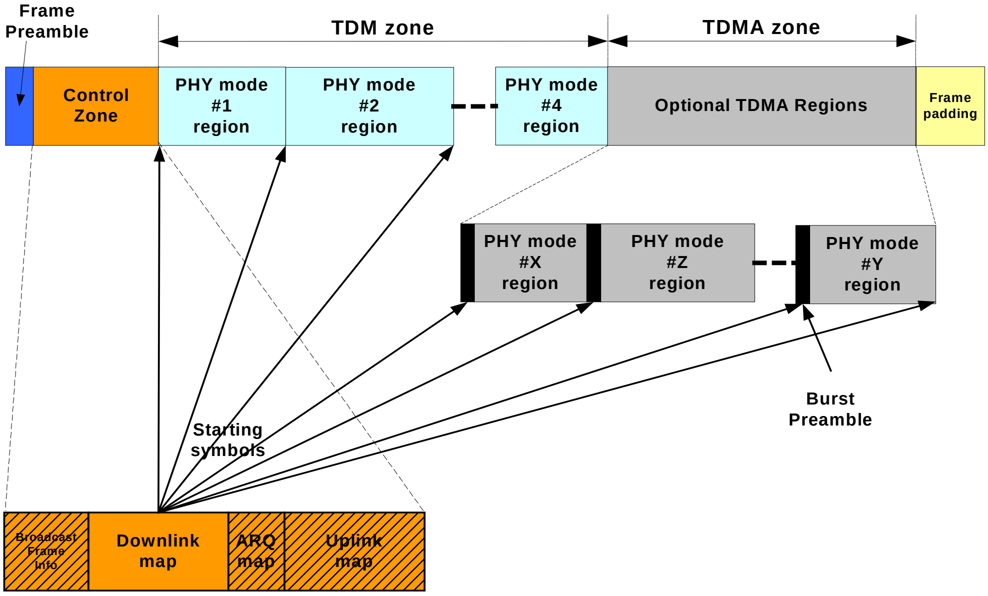

Figure 3: Basic DL frame structure

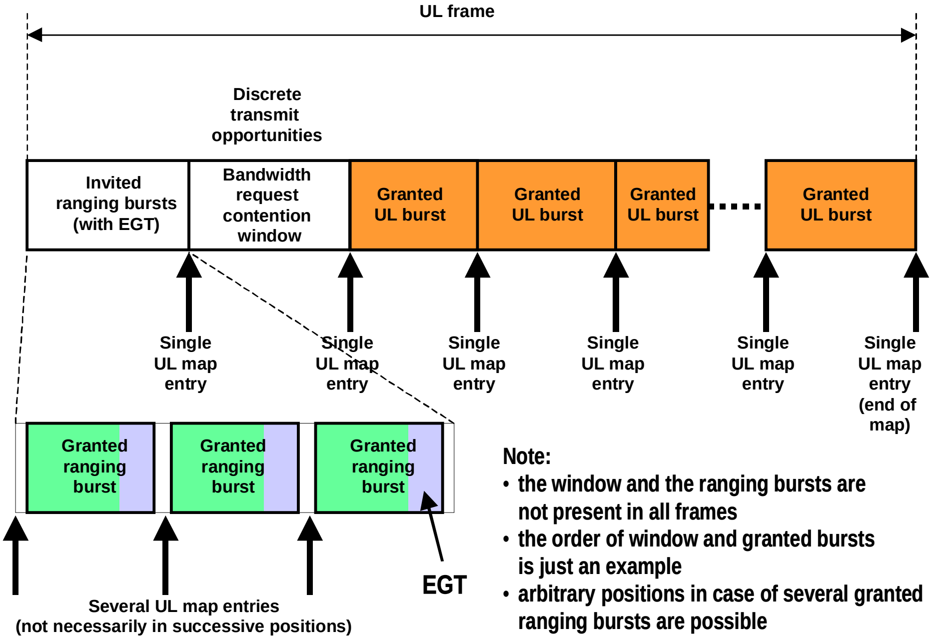

Figure 4: Basic UL frame structure

The DL frame structure is shown in Figure 3. The control zone (CZ) after the DL frame preamble consists of some broadcast information fields, the DL map, the ARQ map and the UL map. The four PHY mode regions in the TDM zone are ordered according to decreasing robustness (i.e., increasing efficiency) from QPSK to 64-QAM transmissions. Each PHY mode region contains one or more FEC blocks, and each FEC block carries up to four MAC PDUs for the same or different ATs. The DL map contains the DL Interval Usage Code (DIUC, identifying the PHY mode) and the Starting Symbol (SS) of the region. The AT decodes all PHY mode regions between the most robust region and the currently allocated highest region and discards all MAC PDU (according to CID in the MAC PDU header) that are addressed to other ATs.

The optional TDMA zone in the DL frame is very similar to the TDM zone. The differences are that the PHY mode regions can be in any order and that each region contains a preamble. The purpose of the TDMA zone is to give H-FDD ATs which have transmitted earlier in the UL frame (and thus lost DL synchronization) the possibility to re-synchronize with the DL and receive data. It should be noted that also without the TDMA zone, H-FDD ATs can be supported (in this case the AP has to schedule DL data for these ATs before their UL grants in each frame).

The UL frame structure is shown in Figure 4 and consists of granted UL bursts of arbitrary order. An UL burst starts with a guard time and a preamble, followed by a sequence of FEC blocks (with the same coding and modulation), where each FEC block carries up to four MAC PDUs. Of course, the MAC PDUs are from the same AT but can carry payload or control information for different connections. The UL map in the DL control zone carries triplets of UL Interval Usage Code (UIUC, identifying the PHY mode to be used), one SS and a 10-bit Terminal Identity (TID). Usually, an AT is granted only one UL burst per frame, and the number of granted PDUs is computed from the difference between the SS and the next SS, taking into account the UIUC. It is also possible to grant so-called short PDUs with 8 byte (instead of 51 byte) payload for messaging purposes. Specific entries in the UL map are used for granting specific ranging bursts and a contention window for bandwidth requests. Summarizing,

DL map = sequence of (DIUC,SS),
UL map = sequence of (UIUC,TID,SS).

3.3 ARQ

PMP systems in dense constellations with small frequency re-use factor could suffer from co-channel interference.

- For the DL, the interference will be limited because of the narrow-beam AT antenna. Furthermore, the interference will be time-invariant since the APs transmit continuously and with constant power (in contrast to UL).
- However, for the UL, the interference will be typically time-variant and could also be much larger than in the DL. This could make the use of efficient UL PHY modes with 16-QAM nearly impossible. This problem can be avoided by a more conservative frequency planning (i.e., larger frequency re-use factor) or by using ARQ for the UL. Obviously, the application of ARQ is only reasonable if the number of MAC PDUs for re-transmissions is small.

The principle of ARQ for HA systems is based on a specific selective-repeat approach as sketched in Figure 5.

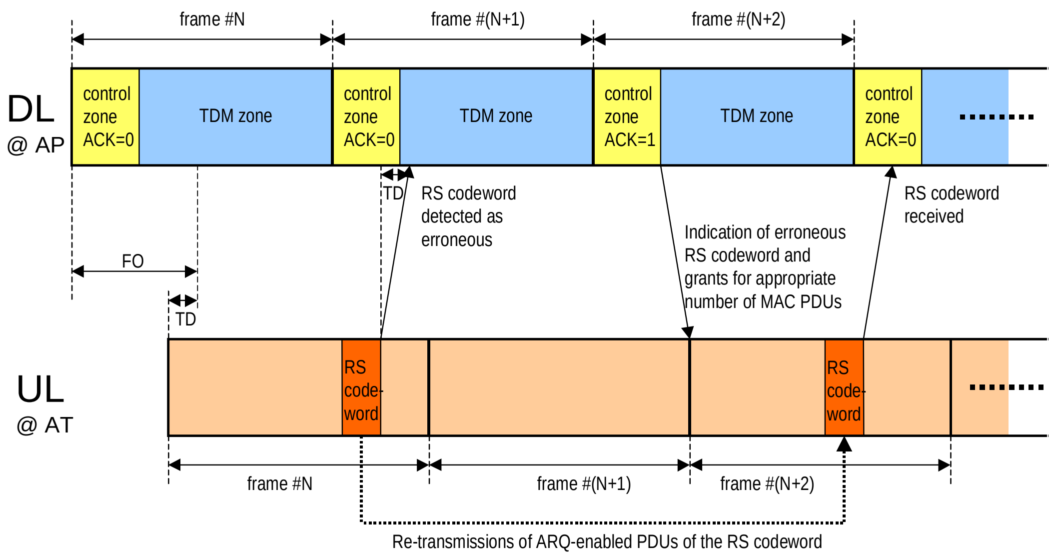

Figure 5: Basic principle of ARQ for UL

In the AP, the received FEC blocks are checked and in case of detected errors (that are not correctable) the RS codeword itself and all MAC PDUs carried by this codeword shall be discarded. If at least one erroneous RS codeword in the UL frame #N is detected (and if the grant for this burst was scheduled to an AT that has at least one ARQ-enabled connection), then the AP set an indication in the ARQ map of the control zone of the DL frame #(N+2). This indication enforces the AT to re-transmit in the UL frame #(N+2) all MAC PDUs for ARQ-enabled connections contained in the erroneous RS codeword. MAC PDUs for non-ARQ-enabled connections are not re-transmitted. ARQ is an optional feature for the AP and is negotiated on a per connection basis.

3.4 Radio Resource Control

The PHY mode is adaptive for DL and UL. The Automatic Transmit Power Control (ATPC) is mandatory for UL and optional for DL.

- DL: The selection of the PHY mode is under full control of the AP and based on measurements in the AT that are reported to the AP. The highest currently used DL PHY mode is announced to the AT.
- UL: The selection of the UL PHY mode and the AT transmit power are based on the measurements of the received signal in the AP (a minimum traffic load in the UL for each AT is needed for these measurements in the AP and achieved by appropriate grants to each AT). The PHY mode is commanded to the AT in the UL map and the transmit power is commanded to the AT with specific management messages (also containing transmit timing corrections).

The Message Sequence Chart (MSC) for an AT-initiated change towards a more efficient DL PHY mode is shown in Figure 6. The AT sends a measurement report, the AP replies with a change announcement and the AT has to acknowledge this announcement and start to decode more PHY mode regions. After reception of the acknowledgement, the AP starts to send MAC PDUs to this AT in a more efficient PHY mode region.

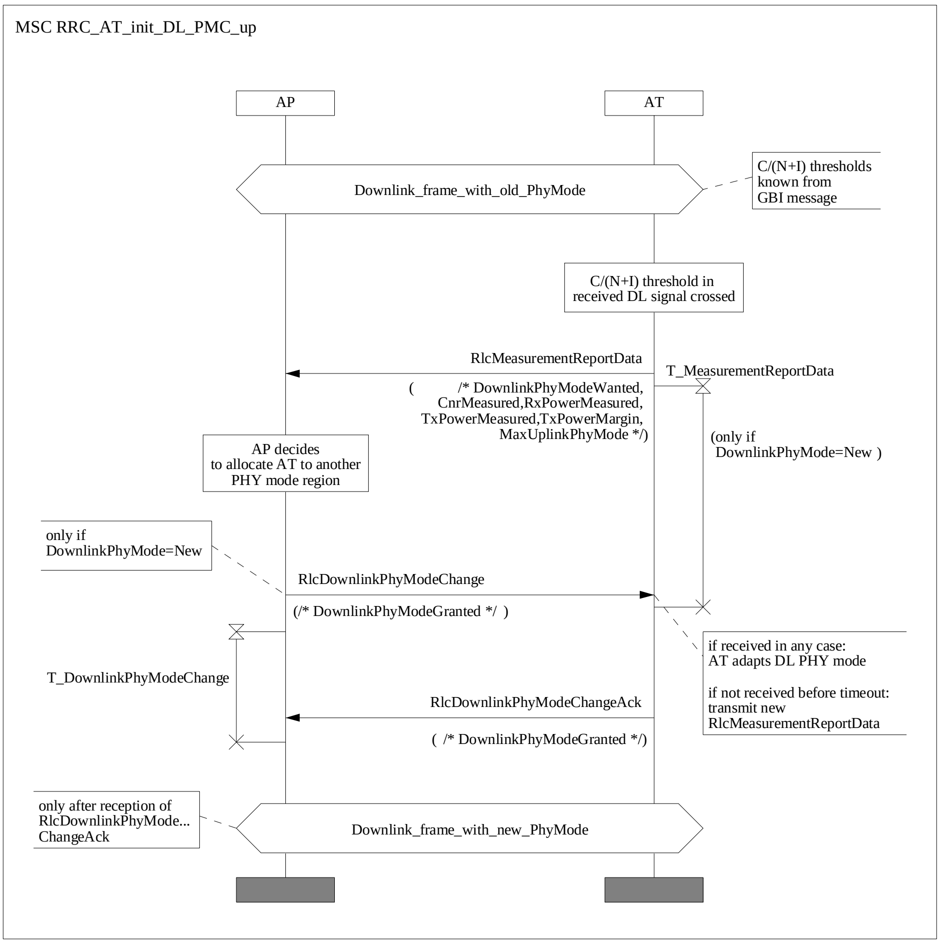

Figure 6: Protocol MSC for the change of the DL PHY mode

3.5 Resource Allocation and Request-Grant Mechanisms

The MAC protocol is a central feature of a PMP system to allocate bandwidth for the shared physical medium. The DL is under control of the DL scheduler in the AP where this has no impact on the air-interface standard. However, the UL is under control of the UL scheduler in the AP and this requires the specification of advanced resource request and grant mechanisms. The ATs transmit in a TDMA fashion, as commanded with the UL map, to avoid collisions.

Connections are grouped into Connection Aggregates (CA), which contain one or more connections. Normally, all connections in a CA are assigned to the same service class. Requests for UL bandwidth are made on a per CA basis (identified by CID), whereas grants to ATs are on a per AT basis (addressed per TID). The resource requests are coded in aggregate form, i.e., the complete queue status of all connections in the CA is reported in the Piggyback (PB) field of the UL MAC PDU header. The header contains also a poll-me (PB) bit and another bit (RSB) that can be used to request a short MAC PDU. Requests (for up to three CAs) are also possible with a specific bandwidth request message that can be sent in the bandwidth request contention window or in granted UL bursts. The contention resolution algorithm is based on a truncated binary exponential backoff algorithm, where the initial and maximum backoff window sizes are controlled by the AP. Furthermore, the AP can request a report on the queue status of up to six CAs with a specific message.

3.6 Connection Control

The creation (setup), modification (change) or deletion of connections can be initiated by AP or AT. This is accomplished through a series of MAC management messages that have been defined. The following rules shall be applied:

- The AP has all necessary knowledge to determine what has to be done at any time as far as the connection establishment or change or deletion procedures are concerned. The AP shall either approve or disapprove all connection management proposals by the AT.
- Either the AP or the AT can initiate a connection termination procedure only in response to the reception of a deletion primitive from the higher layers (except for re-initialization procedures). The connection deletion procedure priority is higher than all other connection control procedures.

During the setup of a connection the QoS parameters for the MAC PDUs exchanged on this connection are implicitly defined (see Section 1 for the four service categories on the DLC level).

Figure 7 shows the protocol primitives Rlc... (and in addition the service primitives Dlc... between DLC layer and CL, but these are only informative and not a normative part of the HA standard) for a setup of a connection under initiative of the AT.

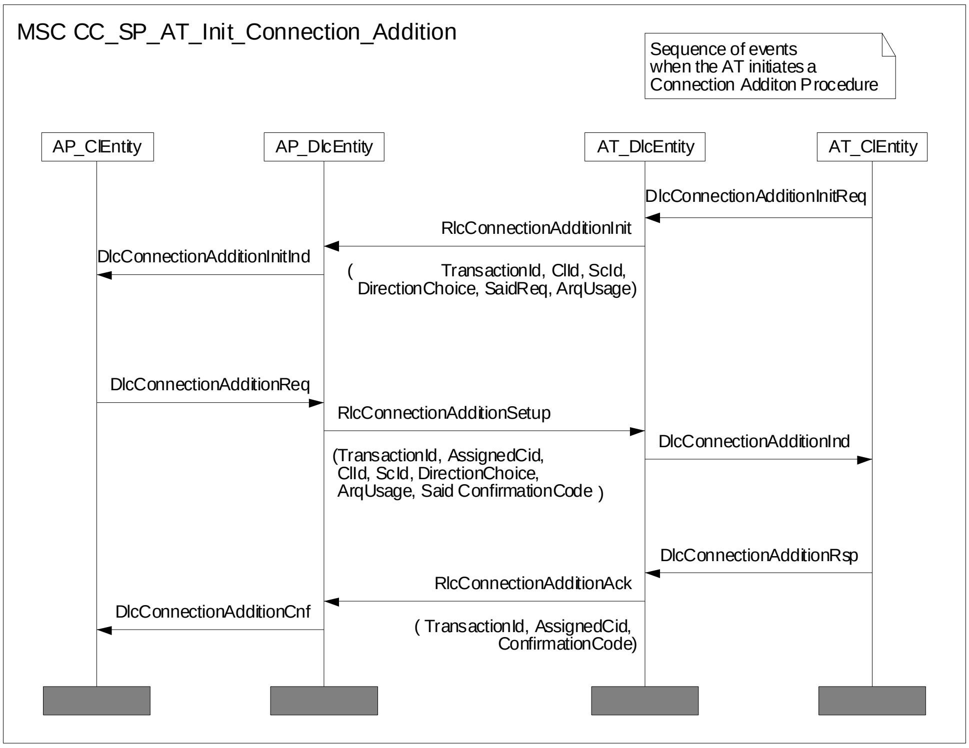

Figure 7: Protocol MSC for AT initiated connection set up

Clid is information about the CL type, Scid about the service class type, Said about the SA identity (see Section 3.7) and the parameter ArqUsage is used to request (UL) and command (DL) the application of ARQ for the respective connection.

3.7 Security Functions

The most important security requirements include the protection of traffic privacy, the prevention of fraud and checks for legitimate use of ATs. In addition to the security mechanisms applied on the HA radio link, high-security applications may use their own end-to-end security mechanisms implemented on higher layers. As a consequence, a protection against active attacks (e.g., message integrity protection) is not provided by HA systems. The key mechanisms and protocols for security control are as follows:

- The authentication of ATs is based on X.509 certificates, see ITU-T X.509 (2000).
- Three-level cryptographic scheme:
    - asymmetric RSA, used for authentication and to encrypt AK (Authentication Key) for the transmission to the AT.
    - symmetric AK, used to encrypt (with triple-DES) TEK (Traffic Encryption Key) for the transmission to the AT.
    - symmetric TEK, used for the encryption of the payload part of all unicast traffic connections in DL and UL (all management connections and all broadcast and multicast connections are not encrypted).
- Frequent changes of keys are possible during traffic transmission. A lifetime for AK and TEK is applied.

The concept of Security Associations (SA) is restricted to one TEK per direction per AT at the same time and one AK per AT at the same time. Encryption and all security functions can be switched off (e.g., to allow the operation of HA systems when encryption is legally not allowed).

3.8 Initialization

Initialization is the procedure that occurs when an AT enters into the network. At the end of the initialization process the AT becomes operational. Initialization is a general term that includes not only the first access of an AT to the network but also the re-access after power supply interruption or link interruption due to deep rain fading. The initialization is always invited, i.e., the AP knows the AT MAC address in advance and the AP knows when to perform an initialization procedure.

The steps of the initialization process are shown in Figure 8 as a High-level MSC (HMSC). The ranging process is required to get the correct timing and transmit power settings for the normal operation. Using specific granted UL ranging bursts with extended guard time (up to 80μs), the AT sends ranging request messages with continuously increasing transmit power (starting from minimum power) until a response in the DL commands the correct settings. After deep rain fading events, this process will typically be performed under poor link conditions. Nevertheless, in order to achieve robustness and re-initialization as fast as possible, the ranging process (hidden behind a small box in Figure 8) is truly a very complex procedure, see ETSI TS 102000 (2002).

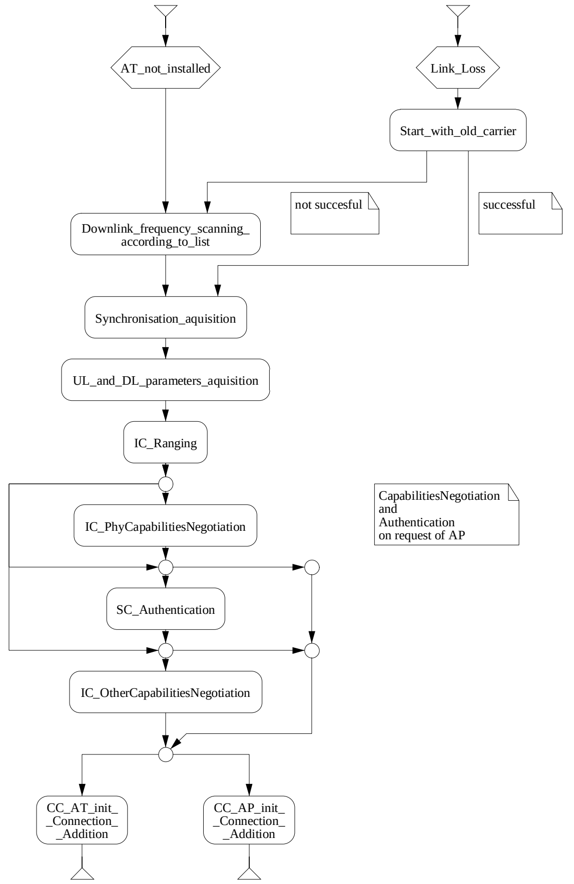

Figure 8: HMSC of initialization steps

4. PERFORMANCE OF HA SYSTEMS

The maximum and minimum data rates per RF carrier and sector are summarized in Figure 9 for HA systems operated with the FDD mode.

- Maximum data rate (best-case) requires highest PHY mode (64-QAM in DL, 16-QAM in UL), i.e., typically clear-sky conditions without any interferences from other sectors; furthermore short control zone (DL); always four MAC PDU per FEC block (UL); short burst preamble (UL).
- Minimum data rate (worst-case) results from most robust PHY mode (QPSK in DL and UL), i.e., typically in case of rain fading and/or strong interference from other sectors; furthermore maximum length of control zone (16 RS blocks of 30 bytes, DL); maximum number of ATs with

only one MAC PDU per frame (124 ATs, UL); long burst preamble (UL).

We refer to Fazel (2002) for details on PHY modes and PHY mode sets. The length of the control zone in number of FEC blocks is denoted by |CZ| in Figure 9.

It should be mentioned that rain fading affects the C/N (Carrier-to-Noise) ratio for DL and UL directions in the same way, and reduces the C/I (Carrier-to-Interference) ratio at the same time. For large cellular constellations, interference effects are larger in outer than inner sectors for the DL direction, but vice versa for the UL. High UL capacity causes longer control zones and thus a reduced DL capacity. So, the capacity calculation of a HA sector is a complex matter. The typical data rates are somewhere between the two extreme cases, typically 35...60 Mbit/s (DL) and 30...40 Mbit/s (UL). Usually, guarantees for CBR traffic should respect the worst-case conditions.

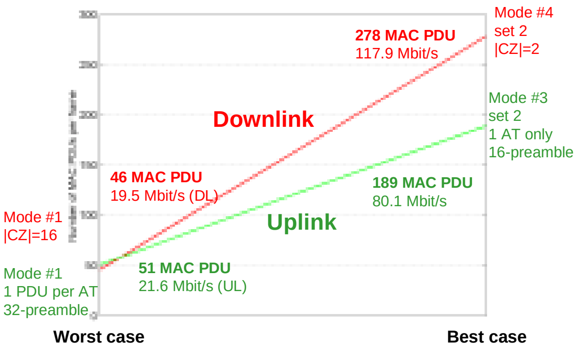

Figure 9: Maximum and minimum data rates

5. SPECIFICATION APPROACH TO GUARANTEE INTEROPERABILITY

BRAN HA is a specification for an interoperable standard, thus both the normal (i.e., errorfree messaging) and exceptional (i.e., errors, missing or delayed messages) behaviour of the system is specified in detail. The approach used for the IEEE 802.16 standard for BWA is described in (Stanwood, 2002).

5.1 General Overview and Specification Languages

The TS of the BRAN HA DLC layer is based on standardized specification languages (see ITU-T X.680; X.691; Z.100; Z.120) in addition to the textual description and informative figures. The heart of the standard is the specification of protocol messages and their formats in ASN.1 (ITU-T X.680). The exceptional behaviour is described in full detail by Message Sequence Charts (MSC) including also all timers and by High-level MSC (HMSC), see (ITU-T Z.120). The normative protocol behaviour specification is given in SDL models (ITU-T Z.100) covering all key protocol aspects. The HA SDL models were extensively validated using state exploration tools. The validation results demonstrate the absence of a number of undesirable properties such as deadlocks, livelocks and similar. The SDL models can also be simulated in such a way that protocol traces shown as MSC diagrams can be generated and examined. Such SDL models represent a reference implementation of the protocol. However, it is important to note that this level of precision in describing the protocol behaviour still leaves many implementation choices open as long as the normative protocol behaviour is respected.

5.2 Specification of Protocol Message Formats

About 50 protocol primitives are defined in ASN.1. For the concrete (transfer) encoding the Packed Encoding Rules (PER) with byte alignment are applied (ITU-T X.691). As example an extract of the ASN.1 specification is shown in Table 2.

Table 2: Example of ASN.1 message specification

```
RlcGeneralBroadcastInformation ::= SEQUENCE {
  duplexMode                    DuplexMode,
  frameOffset                   FrameOffset,
  tdmaZoneDownlink              TdmaZoneDownlink,
  encryptionMode                EncryptionMode,
-- ...
  phyModeSetDescriptorCurrent   PhyModeSetDescriptor,
  phyModeSetDescriptorFuture    PhyModeSetDescriptor
                                                 OPTIONAL}

PhyModeSetDescriptor      ::= SEQUENCE {
  psdi                          Psdi,
  downlinkPhyThresholdsList     PhyThresholdsList,
  uplinkPowerModChangeListNonTc UplinkPowerModChangeList,
  uplinkPowerModChangeListTc    UplinkPowerModChangeList}

Psdi                      ::= INTEGER(0..15)

PhyThresholdsList
  ::= SEQUENCE (SIZE(2..7)) OF PhyThresholdPair
PhyThresholdPair  ::= SEQUENCE {
  upThreshold    CnrThreshold,  -- quality increase
  downThreshold  CnrThreshold } -- quality decrease

UplinkPowerModChangeList
  ::= SEQUENCE (SIZE(1..6)) OF UplinkPowerModChange

UplinkPowerModChange::= INTEGER(0..32)
  -- granu=0.5dB, range=[-8,8]dB
CnrThreshold          ::= INTEGER(0..255)
  -- granu=0.25dB,range=[ 4,40]dB
```

The choice of ASN.1 and standardized (PER) encoding rules facilitated and speeded up the development of the protocol specification. However, this is less important in comparison with the fact that it will increase the productivity of product development as well as it's precision since encoder/decoder functions can be generated using ASN.1 compiler tools. Last, but certainly not least, ASN.1 based mechanisms for protocol extendability in future releases, make the standard open for easy future upgrades, allowing even the different future protocol versions to interoperate.

5.3 Test Specification

ETSI test specifications are designed to concentrate on areas critical to interoperability, including testing an implementation's reaction to erroneous behaviour. The goal is conformance testing for interoperability. For over 10 years ETSI Technical Bodies have been producing test specifications for key technologies such as GSM, 3GPP, DECT, INAP, TETRA, ISDN, B-ISDN, HiperLAN2, VB-5, FSK and VoIP (to name but a few). The track record of the mentioned technologies in terms of interoperability has been very good. The proven methodology of producing test specifications contributes in many ways to securing that products implementing the standard are interoperable. The major advantages of the ETSI approach are summarized below:

- The test specification development is controlled by the same body that defined the base standard in a fair and transparent way.
- The development of the test specifications gives valuable feedback to the base standards.
- The equipment claiming compliance to the standard can be tested to demonstrate that compliance.
- Guarantee that AP and AT equipment from different vendors is tested in the same way, and to the same interpretation of the standard.

6. CONCLUSIONS

The ETSI BRAN HA standard for interoperable PMP systems above 11 GHz defines TSs for the PHY layer, the DLC layer, several convergence layers for IP and ATM and also normative test specifications. The normal and exceptional behaviour of the system and especially the messaging is specified in detail. The PHY and DLC documents were approved by ETSI in February and April 2002, respectively.

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BIOGRAPHIES

Bernd Friedrichs graduated in mathematics and computer science with a Dipl.-Math. degree from the Technical University of Braunschweig, Germany, in 1980. He received the Ph.D. degree in electrical engineering from the University of Erlangen, Germany, in 1990. Since 1980 he has been with AEG-Telefunken, ANT Telecommunications, Bosch Telecom, and now Marconi Communications in Backnang, Germany. He is also a lecturer at the University of Karlsruhe, Germany, teaching error-control coding and information theory. He has authored a textbook on the theory and applications of coding. He was working on adaptive filters, digital receivers, mobile radio, cryptography for railway control via GSM-R (project DIBMOF), software-defined radio (ACTS project FIRST), fixed wireless access, and ATM & IP over radio. Currently, he is Rapporteur for the HA DLC layer of ETSI BRAN.

Massimiliano Buscato received his Electronic Engineering (Telecommunications) degree from the Polytechnic University of Milan in 1998. Afterwards he joined Ericsson Telecommunication Italy as System engineer. Currently he is with Ericsson Lab Italy (R&D) working on system aspects relevant to Wireless Broadband Access Systems and in particular on DLC (Data Link Control) layer protocol, network synchronization and network protection. Since 2001 he is attending ETSI BRAN meetings.

Giulio Cavalli graduated in Telecommunication Engineering in 1999. After brief experiences as a software designer, he joined Siemens ICN S.p.A (now Siemens Mobile), where he worked as system engineer and member of the technical staff. His major experiences are Radio Point-To-Multipoint, VoIP and ATM. He participates in various standardization groups within ETSI. He is now Rapporteur for the Convergence Layer within ETSI BRAN Hiperacess group.

Per Emanuelsson received a Master of Science in Engineering Physics and a Ph.D. in Solid State Physics from the University of Lund, Sweden , in 1986 and 1991, respectively. In 1993 he received an Alexander von Humboldt grant and stayed one year at the Technical University of Munich where he continued his research within Semiconductor Physics. In 1995 Emanuelsson joined Telia Research. At Telia Research he has been working with fixed and mobile radio access systems. He has participated in ETSI BRAN since its start in 1997. He acted as vice chairman and HiperAccess co-ordinator within ETSI BRAN from 1999 to 2002.

Juha Salokannel received his M.Sc. degree in electrical engineering from Tampere University of Technology, Finland 1998. The same year he joined Nokia Mobile Phones and started to participate the development and standardization work of the HiperLAN/2 system. From year 2000 on he has been working in Nokia Research Center, Finland, as Senior Research Engineer. His current research interests are in various Personal, Local and Metropolitan Area wireless networks.

Ken Stanwood graduated with a Bachelor's of Science degree in Mathematical Sciences from Oregon State University in 1983, and a Master's of Science degree in Computer Science from Stanford University in 1986. He has held various positions with communications companies throughout his career. Mr. Stanwood is currently Principle Member of Technical Staff and Manager of Systems Engineering at Ensemble Communications in San Diego where he was the primary designer of the MAC and transmission convergence (TC) layers of Ensemble's proprietary AdaptixTM broadband wireless access system. He has additionally had significant influence on the physical layer.

Stefan Wahl received the Dipl.-Ing. degree in electrical engineering from the University of Saarbruecken, Germany, in 1987. In the same year he joined the Alcatel SEL AG Research Center in Stuttgart, Germany, participating in the RACE program where the main tasks were developing an ATM switching concept and investigations on traffic performance. Since 1989 he was first designing and later validating the ATM switching element ASIC. Between 1996 and 2000, he was working on HFC based broadband access network technologies and was project leader of ACTS/AROMA project. Currently he is responsible for the MAC and IP layer system design of future LMDS system.

Milan Zoric received a Dipl.-Ing. diploma in Electrical Engineering and M.Sc. in Telecommunications and Information Technology from University of Zagreb, Croatia in 1972 and 1982 respectively. His work has been related to SDL and its use since early eighties. Working in telecomm industry and Faculty of Electrical Engineering in Zagreb, Croatia, he worked in numerous research and development projects where SDL was applied. He participated in the validation of SDL formal semantics in 1988, published numerous papers related to SDL and led a team developing an SDL tool. Since 1995 he has participated in a number of ETSI projects related to the use of SDL in standardisation and worked as consultant for other international companies. Since September 1998 Milan Zoric is a member of a team of experts at the European Telecommunications Standards Institute known as the Protocol and Testing Competence Centre or PTCC. During the four years large portion of the work was devoted to HiperLAN2 and Hiperaccess standardisation. Current activities also include the responsibility for Z.105 (SDL combined with ASN.1 modules) in ITU-T.