HiperLAN/2 Ad Hoc Network Configuration By CC Selection

Jörg Peetz, Andreas Hettich, and Ole Klein,
Aachen University of Technology, Communication Networks, Germany

Abstract

The HiperLAN Type 2 (H/2) standard developed by the European Telecommunication Standards Institute (ETSI) supports two profiles, Home Environment Extension (HEE) and Business Extension. With the HEE profile a 'one hop'-ad hoc network configuration, a so called single subnet, is provided. All devices participating in such an H/2 subnet operate on the same frequency channel whereby the channel access is coordinated by a Central Controller (CC) that is an H/2 terminal itself. All H/2 home devices (CC-capable) are able to perform the CC specific functions in addition to general terminal functions. During the network establishment phase or whenever an active CC is lost, a new CC must be selected among all CC-capable terminals forming the subnet. In general, each terminal first tries to join an existing wireless network by scanning frequencies for an active CC. If no association to any CC is possible, the CC Selection is started. This collision resolution mechanism is performed in a decentralized way by every terminal. It consists of alternating probing and frequency scanning phases. Based on the result of the CC Selection algorithm each CC-capable device decides on its own whether to become a wireless terminal (WT) or to take over the CC functionality. This paper presents the CC Selection concept, a performance analysis, the validation of system parameters and a comparison to the master election in Bluetooth Piconets.

1 Introduction

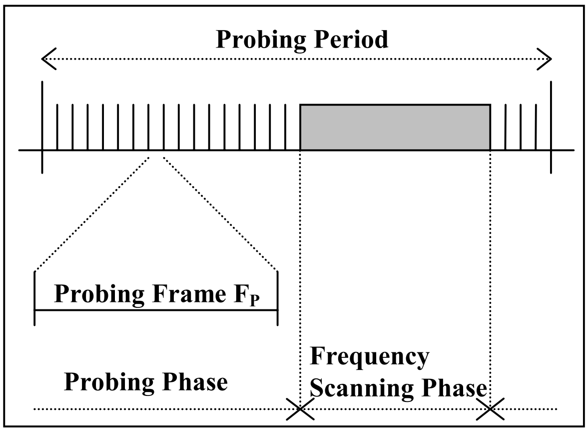
The intention of the ETSI project BRAN (Broadband Radio Access Networks) for developing the HiperLAN/2 standard was to provide wireless Internet, Intranet and Multimedia services to the user [11]. H/2 meets these requirements, it supports transmission rates up to 54 Mbit/s by using the Orthogonal Frequency Division Multiplex (OFDM) modulation technique within the PHY layer. The medium access control (MAC) protocol is organized centrally so that for every MAC frame a defined capacity can be allocated to a user. The data transmission is connection oriented whereby a time division multiple access (TDMA/TDD) method is used to support uplink, downlink and direct link connections [6]. Specific QoS requirements can be supported for each connection. All signalling functions, e.g. for establishment of user connections, are handled by the Radio Link Control (RLC) Protocol [9]. For the adaptation of the service requirements of different higher layers the H/2 protocoll stack contains common part convergence layers for packet based [8] and cell based data transmission and service specific convergence layers for Ethernet, IP, IEEE 1394 and UMTS. Beside the infrastructure operation mode, already defined in the specification of the DLC basic functions [6], the communication between home devices including the support of IEEE 1394 is another purpose of H/2. Therefore the Extensions for the Home Environment (HEE) have been specified. In contrast to the cellular network configuration provided by the DLC basics, an ad hoc network configuration has been chosen for the H/2 HEE to allow an operation in plug-and-play manner [7]. The H/2 HEE follows the idea of a centralized one hop ad hoc network, a so called single subnet. The medium access of the different terminals is coordinated by a Central Controller (CC) meaning an H/2 device in an especial state. This CC functionality can be taken over by all CC-capable devices. Since several terminals are able to become a CC, a decision is necessary. The process of the dynamic selection of a CC among the CC-capable terminals is the topic of this paper. The dynamic CC Selection ensures that within one subnet only one CC is established. It is performed in a decentralized and autonomous way by each CC-capable device when it is powered on or when the CC is lost. This algorithm is novel and specifically designed for H/2 ad hoc networks. The concept, however, can be applied for all centralized ad hoc environments.

2 Dynamic CC Selection Concept

When a CC-capable device is powered on, it expects first to become a WT and to associate to an already present CC. Therefore it scans all available frequencies to detect running CCs (initial scan process). A running CC manages the access to the frequency channel using a fixed MAC frame structure containing uplink, downlink, direct link and random access phases. Each MAC frame is introduced by a Broadcast Control Channel (BCCH) with a unique format enabling new terminals to detect the CC. If a CC has been detected the CC-capable device tries to associate. In case the association procedure fails, e.g. because the CC belongs to a neighbouring subnet, the frequency scanning is continued. If all frequencies have been scanned without successful association, the dynamic CC selection procedure is started.

Two main problems must be considered and solved for a successful selection of only one CC within the subnet. First, the collision of signals sent by different CC candidates has to be managed. Second, it has to be ensured that all CC candidates can receive each other. Therefore two phases of the CC Selection process, the probing phase and the frequency scanning phase are needed, see **Fig. 1**. During the probing phase the CC candidate transmits probing beacons to notify the other devices. During the frequency scanning phase, however, it tries to detect further CC-capable devices operating on other frequency channels.

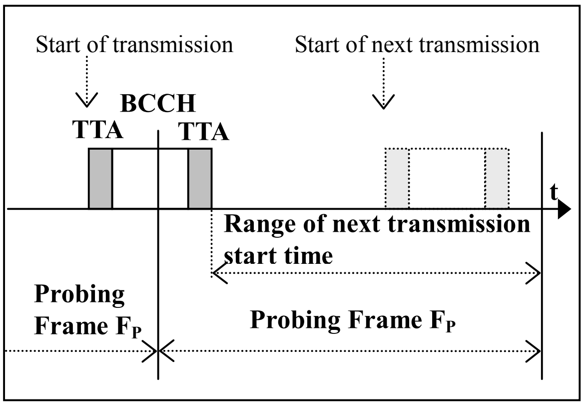
Fig. 1 CC Probing Period



The first problem is originated by the decentralized selection concept. Each CC-capable device entering the CC Selection process tries to become a CC. The contention among the CC-capable devices by transmitting beacon signals is called CC Probing. It is deduced from the ALOHA protocol [14] [13] [1] [2], i.e. transmitted packets may collide but are repeated until they are received. Please note, a S-ALOHA concept with synchronized probing phases cannot be applied because of different time bases and switch on times of the involved terminals.

The probing phase is subdivided into so called Probing Frames, whereby a CC-capable device sends one beacon signal per Probing Frame to indicate the attempt of becoming CC to other devices. Since for this beacon signal the same structure has been chosen as for the BCCH of a running CC, it is called Probing BCCH. The Probing Frame (virtual frame, not identically to the MAC frame) does not only include the beacon transmission, but also phases at which the device senses the Probing Frequency channel. Since several terminals may execute the CC Selection procedure at the same time on the same channel, e.g. with the lowest interference level, a collision of the Probing BCCHs of two or more terminals may occur. In order to avoid such collisions the start time of the Probing BCCH is randomly chosen. **Fig. 2** shows a CC Probing Frame F_P. Since F_P is the upper limit of this timer, a Probing BCCH can overlap into the next CC Probing Frame. In this case the start of the next Probing BCCH transmission is restricted to the range from the end of the finished transmission up to the end of the Probing Frame.

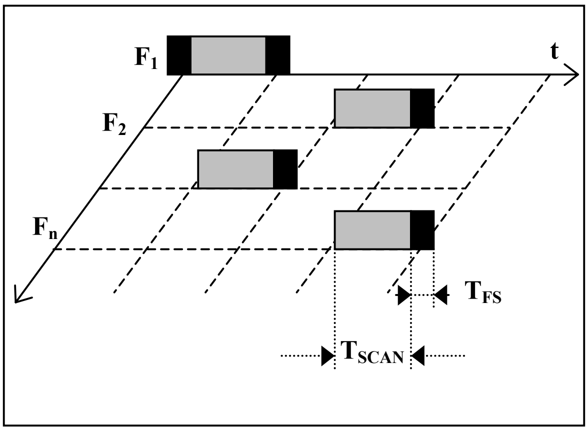
Fig. 2 Overlapping BCCH, Next Transmission



To cope with the second problem, i.e. two or more CC candidates do not receive each other, probing phase and frequency scan phase, that form together the Probing Period, are repeated several times. Thus a high probability of selecting only one CC is ensured even if two CC-capable terminals do not find each other in one period because of scanning frequencies at the same time. The beginning of the frequency scanning phase is determined by random to avoid steadily overlapping scanning processes of different terminals.

Fig. 3 depicts the frequency scanning phase performed within a Probing Period, see also **Fig. 1**. A CC-capable device scans all available frequencies for CC Probing BCCH except the last Probing Frequency. In Europe HIPERLAN/2 is limited to a maximum number of 19 frequencies allocated in the 5 GHz band. In the US and Japan a lower number of frequencies (12, 4) are supported. The Frequency Switching Time T_{FS} is the maximum time it takes to switch to another frequency channel that is defined in [5] as 1 ms. The Frequency Scanning Time T_{SCAN} determines the duration a CC-capable device needs to scan another frequency channel for a CC Probing BCCH. In order to ensure that the BCCH can be detected completely, the duration T_{SCAN} has been defined to be 1 ms corresponding to two Probing Frames of 500 µs each. After scanning a frequency the CC-capable device immediatly switches to the next frequency. The order of the frequencies is randomly chosen per scanning phase.

Fig. 3 Frequency Scanning



Each CC-capable device which senses a Probing Beacon during the probing or the frequency scanning phase withdraws from the CC Selection, performs a back-off to await the result of the CC Selection process and starts again with the initial scan process to find the new CC. Since in the worst case the detected terminal just started the CC Selection process, the back-off time is required to be as long as the complete process duration. Finally the CC function is assigned to that CC-capable device which has not sensed anything for the complete CC Selection process. This device 'survives' and changes into the CC operation mode.

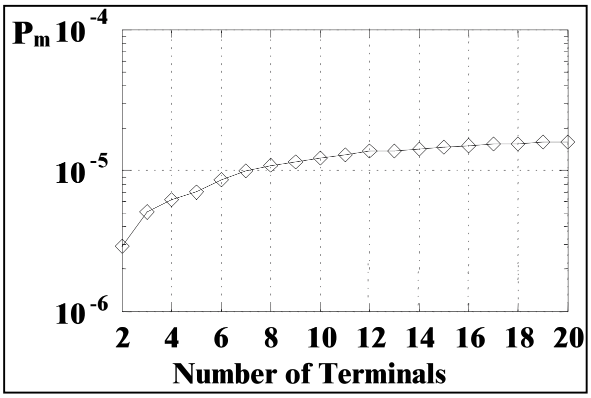
3 Performance of CC Selection

3.1 Probability of Multiple CCs

The probability P_m of more than one terminal deciding to be the CC has been calculated to evaluate an optimum set of parameters and the results have been validated by simulation. For the parameters specified in H/2 (Probing_Period_Duration = 100 ms, Number_of_Periods = 10) a probability P_m of 10^{-5} is achieved as shown in **Fig. 4**. This probability has been found to be acceptable for home users.

The guarantee of a very low probability P_m is essential for H/2 ad hoc networks because the operation of more than one CC on the same frequency induces errors and interference situations that can only be resolved by the restart of all terminals.

Fig. 4 Probability of more than one CC in a Subnet

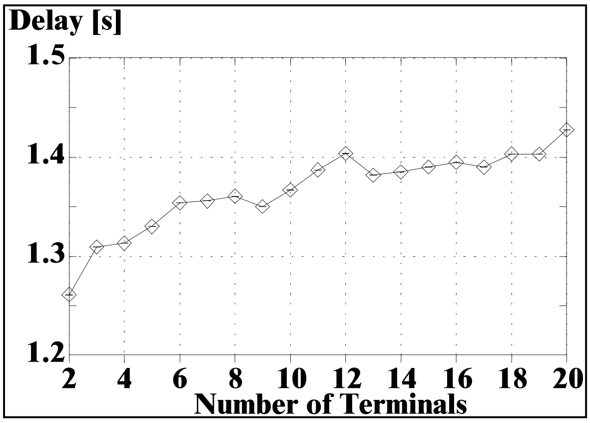


The number of terminals involved in the CC Selection depends on the initial scenario. In case of the creation of a new H/2 subnet it is most likely to find only two or three terminals competing first, while the remaining terminals will join the subnet after a CC has been assigned. In case the CC is lost, e.g. because of power-off, all terminals of the subnet will start the CC Selection at the same time, so perhaps 10 or 20 terminals are involved. **Fig. 4** displays the probability P_m over the number of terminals involved showing a slight increase of P_m from the minimum of $3 \cdot 10^{-6}$ for two terminals to the upper limit of $2 \cdot 10^{-5}$ for twenty terminals and more.

3.2 QoS Aspects – Delay per WT

The relevant parameters influencing the QoS of the CC Selection algorithm are the probability P_m and the delay of terminals caused by the CC Selection algorithm. These parameters depend on the assumptions made for the number of available frequencies and involved terminals. Both P_m and the delay improve with the reduction of frequencies. In order to consider the worst case, all investigations presume the maximum of 19 available frequency channels. On that condition the terminal 'winning' the contention and becoming CC is delayed for 10 periods plus the initial scan process, i.e. 1.095 s. All other terminals leave the CC Selection procedure later because of the back-off required after detecting another CC candidate. The delay of the WT leaving the CC Selection at last is depicted in **Fig. 5**. The represented delays are mean values that may be exceeded in case of a long competition among the residual CC candidates.

Fig. 5 Delay of the WT last leaving CC Selection



Regarding all involved terminals this diagram defines a mean upper bound of the delay range. The increase of the delay with a larger number of terminals is recognizable. However, the delay is approximately saturated for more than 12 terminals.

3.3 Validation of System Parameters

In case of only two H/2 devices participating in the CC Selection process a formula approximating P_m was calculated to be:

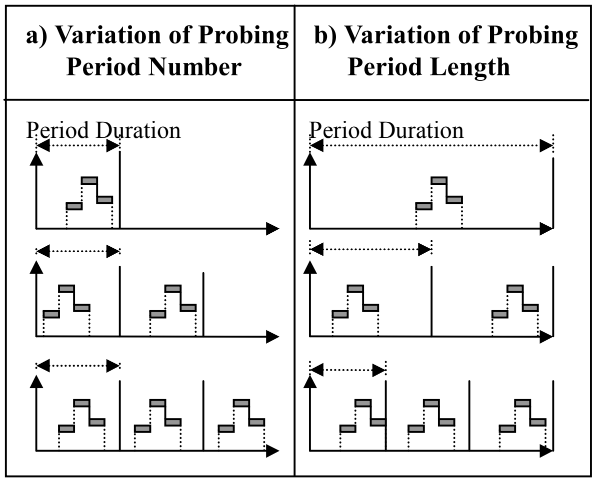
$$P_m = \left[\frac{T_F}{T_P}\right]^N ;N = \frac{T}{T_P}$$

T = *CC Selection Process Duration*
T_P = *Probing Period Duration*
T_F = *Frequency Scanning Phase Duration*
N = *Number of Probing Periods*

Based on this approximation, the minimum value of P_m can be achieved for $T_P = \boldsymbol{e} \cdot T_F$. With 19 frequency channels available, a frequency switching time and a scan interval T_{SCAN} of 1 ms each, every frequency scan phase T_F lasts 37 ms. Thus a Probing Period duration of 100 ms fulfils the requirement of a T_P/T_F ratio close to $\boldsymbol{e}$.

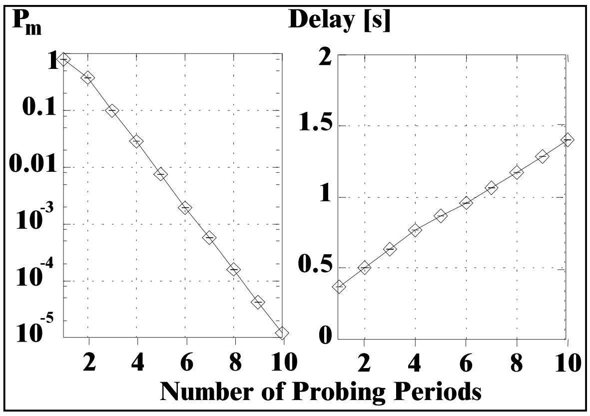
In order to determine and optimize the relevant H/2 specific parameters of the CC Selection algorithm two series of simulations have been investigated. First the number of consecutive Probing Periods has been incremented starting from 1 Period up to 10 Periods while the Probing period duration is fixed at 100 ms. In this case the overall CC Selection process duration increases step-by-step. Second a fixed overall process duration of 1s is assumed while the number of Probing Periods is incremented resulting in a step-wise reduction of the Probing Period duration. Fig. 6 depicts the sequence of simulations for both scenarios.

Fig. 6 Variation of relevant system parameters



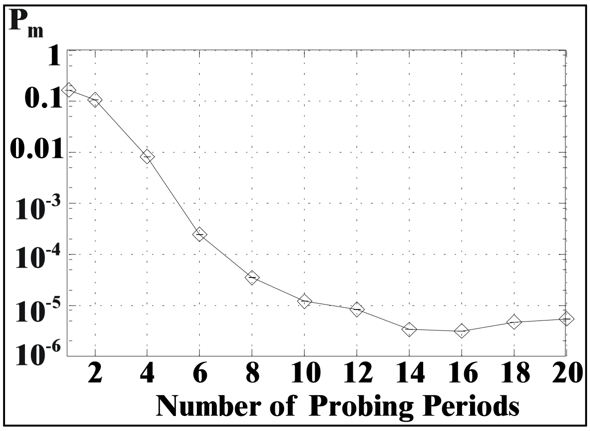
Regarding the variation of the number of Probing Periods for a fixed Probing Period duration, see **Fig. 6a**, the probability P_m of multiple CCs and the mean delay of the last leaving WT have been determined. The simulation results for ten competing terminals are displayed in **Fig. 7** showing P_m decreasing exponentially with each additional period while the corresponding delay increases in a linear way. For ten periods a moderate delay of about 1.4 s for the 'latest' WT combined with a sufficient probability of a successful CC Selection outcome can be achieved.

Fig. 7 Probability P_m and Delay over the number of consecutive Probing Periods



The formula presented to calculate P_m is only valid for two competing terminals. In case of more than two involved terminals the interdependencies among the devices are too complex to be calculated. Simulation results for ten terminals are shown in **Fig. 8**. In contrast to the 'two terminal' scenario, the minimum probability of more than one CC is achieved for about 15 Probing Periods equivalent to a Probing Period duration of 67 ms. For more than 15 Probing Periods a slight increase of P_m is recognizable.

Fig. 8 Probability P_m over the number of Probing Periods for a fixed overall duration



The improvement of P_m for a Probing Period duration of 67 ms compared to 100 ms is relatively small. Assuming two terminals starting CC Selection at the same time to be more likely than ten terminals – this also might happen e.g. in case of a CC loss – the 100 ms Probing Period duration has been standardized.

4 Comparison to the Master Election in Bluetooth Piconets

Bluetooth is a radio interface for the 2.45 GHz frequency band providing short range ad hoc networks. To cope with unpredictable interference situations in the open ISM band a frequency hop spread spectrum technique is applied. Regarding the network topology Bluetooth resembles to the H/2 HEE. So called Piconets are formed by terminals in range of each other [10]. Each Piconet is controlled by a master terminal while all other participating terminals operate as slaves. The master function is assigned to a terminal in ad hoc manner and can be transferred to another device. The Bluetooth Piconet concept is very close to the H/2 ad hoc subnet configuration. The master corresponds to a CC in H/2. Each Bluetooth terminal can take over the master/slave role in analogy to the H/2 CC-capable devices that may operate as CC or WT. An issue planned for the second phase of the H/2 standardization, the interconnection of subnets, is already realized in Bluetooth. So called Scatternets are built from Piconets that establish ad hoc connection between each other.

A new Piconet is created whenever one device within a group of inactive terminals sets up a connection to another device. The initiating terminal automatically becomes master, the destination terminal is assigned the slave role. Each inactive device performs a page scan procedure searching for a calling terminal on a sequence of frequencies determined by the device address and device clock. An active terminal will estimate the clock of the destination terminal and send a page message on the estimated train of frequencies [12]. Since the active terminal does not know the scan time of the destination terminal the page message is repeated several times.

The Bluetooth master election (paging) distinguishes from the H/2 CC Selection because a direct addressing of terminals is possible. In Bluetooth the case of two terminals getting active at the same time is allowed and can be resolved by establishing two connected Piconets. The duration of the Bluetooth paging process, however, depends on the scan intervals. It may take 2.56 s or even longer, if the device clocks are drifting significantly.

5 Conclusions

The CC Selection procedure presented in this paper will be utilised in ETSI-BRAN HiperLAN/2 Home Environment devices. This procedure allows a nearly collision free selection of the Central Controller. The presented algorithm has been simulated and evaluated regarding the probability P_m of multiple CCs and the delay of all involved terminals. The influence of system dependent parameters, e.g. the Probing Period duration, has been validated showing the optimum operating points. A comparison to the master election in Bluetooth Piconets shows the differences between both algorithms and systems despite similar network configurations. Though the CC Selection has been specifically designed for H/2, a transfer to other wireless communication systems with ad hoc network topology and a central access control is possible.

6 Literature

[1] Abramson, N., Development of the ALOHANET, *IEEE Trans. on Inform. Theory*, vol. IT-31, pp. 119-123, March 1985.

[2] Crowther, W., Rettberg, R., Walden, D., Ornstein, S. and Heart, F., A System for Broadcast Communication: Reservation Aloha, *Proc.*

Sixth Hawaii Int. Conf. System Sci., pp. 371-374, 1973.
[3] ETSI, Broadband Radio Access Networks (BRAN), HIgh PERformance Radio Local Area Network (HIPERLAN) Type 2; Requirements and architectures for wireless broadband access, TR 101 031, ETSI, Apr. 1997.
[4] ETSI, Broadband Radio Access Networks (BRAN), HIgh PERformance Radio Local Area Network - Type 2; System Overview, TR 101 683, ETSI, Oct. 1998.
[5] ETSI, Broadband Radio Access Networks (BRAN), HIPERLAN Type 2; Functional Specification; Part 2: Physical (PHY) layer, DTS 0023003-2, ETSI, Oct. 1999.
[6] ETSI, Broadband Radio Access Networks (BRAN), HIPERLAN Type 2; Functional Specification; Data Link Control (DLC) Layer; Part 1: Basic Data Transport Functions, DTS 0020004-1, ETSI, Dec. 1999.
[7] ETSI, Broadband Radio Access Networks (BRAN), HIPERLAN Type 2; Functional Specification; Data Link Control (DLC) Layer; Part 4: Extension for Home Environment, DTS 0020004-4, ETSI, Dec. 1999.
[8] ETSI, Broadband Radio Access Networks (BRAN), HIPERLAN Type 2; Functional Specification; Packet Based Convergence Layer; Part 1: Common Part Functions, DTS 0024004-1, ETSI, Nov. 1999.
[9] ETSI, Broadband Radio Access Networks (BRAN), HIPERLAN Type 2; Functional Specification; Radio Link Control (RLC) sublayer, DTS 0020004-2, ETSI, Dec. 1999.
[10] Haartsen, J., BLUETOOTH - The universal radio interface for ad hoc, wireless connectivity, Available via www from ‘http:\\www.ericsson.se/review/pdf/1998031‘
[11] HIPERLAN/2 Global Forum, Johnsson, M., HIPERLAN/2 - The Broadband Radio Transmission Technology Operating in the 5 GHz Frequency Band, Available via www from ‘http:\\www.hiperlan2.com‘
[12] Specification of the Bluetooth System, Core, Volume 1, Dec. 1999. Available via www from ‘http:\\www.bluetooth.com‘
[13] Tanenbaum, A.S., *Computer Networks*, 2nd Edition. London, UK: Prentice-Hall International, pp. 121-126, 1989.
[14] Walke, B., Mobile Radio Networks. Chichester, Sussex, UK: Wiley & Sons Ltd., 1999.

7 Biography

Jörg Peetz received the master degree in electrical engineering in 1997 from Aachen, University of Technology, Germany. Currently he is working towards a PhD degree at Aachen, University of Technology, Germany. In 1997 he joined the Chair for Communication Networks as a Research Assistant. He has been involved in the ATMmobil subprojects ‘Cellular ATM’ and ‘Wireless ATM LAN’. Currently he works in the ‘Multihop’ project lead by Philips GmbH Aachen within the HyperNET project founded by the German government. This includes the development of protocols for H/2 ad hoc networks. He is involved in the standardization of Broadband Radio Access Networks (BRAN) at ETSI and contributed to the HIPERLAN/2 specifications with focus on the Home Environment Extension.

Andreas Hettich received the master degree in electrical engineering in 1996 from Aachen, University of Technology, Germany. Currently he is working towards a PhD degree at Aachen, University of Technology, Germany. In 1996 he joined the Chair for Communication Networks as a Research Assistant. He has been the project leader of ComNets in the research project 'Wireless ATM LAN' lead by Philips GmbH Aachen within the ATMmobil project. This included the development of protocols for MAC, LLC, autoconfiguration and ad-hoc network management. He was involved in the standardization of Broadband Radio Access Networks (BRAN) at ETSI. With numerous proposals he contributed to the evolving HIPERLAN/2 standard.

Ole Klein works towards the master degree in electrical engineering that he will receive in 2000 from Aachen, University of Technology, Germany. He is involved in the simulation of the H/2 MAC and RLC layer protocols. His work is used in the subproject ‘Multihop’ lead by Philips GmbH Aachen within the HyperNET project founded by the German government.