Paper submitted to

Computer Networks

(reprint EW014 European Wireless 2000)

Name:	Norbert Esseling, Harbinder S. Vandra, Bernhard Walke
Affiliation:	Communication Networks Aachen University of Technology
Address:	Kopernikusstr. 16 D–52074 Aachen, Germany
Tel.:	+49 241 80 79 20
Fax.:	+49 241 88 88 242
E-mail:	es@comnets.rwth-aachen.de

Title:	A Forwarding Concept for HiperLAN/2
Conference Topic:	Wireless LANs

A Forwarding Concept for HiperLAN/2

Norbert Esseling, Harbinder S. Vandra, Bernhard Walke

Communication Networks
Aachen University of Technology
Kopernikusstr. 16
D–52074 Aachen, Germany
E-mail: es@comnets.rwth-aachen.de

Abstract

A new approach to extend the communication range of standard *HiperLAN/2 (H/2)* cells is presented. The basic idea is to use a relay in the time domain that supports terminals outside the range of an H/2 access point. The concept presented employs a novel MAC sub frame structure generated by a new H/2 element called *Forward Mobile Terminal (FMT)* that serves out of range terminals. We present an analysis of the impact of FMTs on the achieved Quality of Service for the H/2 system. Further, the possible service area extension is analysed.

KEYWORDS: ETSI, BRAN, HiperLAN/2, Forwarder, Wireless Base Station

1 Introduction

In the following the so-called *Forwarding Mobile Terminal (FMT)* is presented as the key element to extend the communication range of an *Access Point (AP)* of the *HiperLAN/2 (H/2)* system [1][2][3].

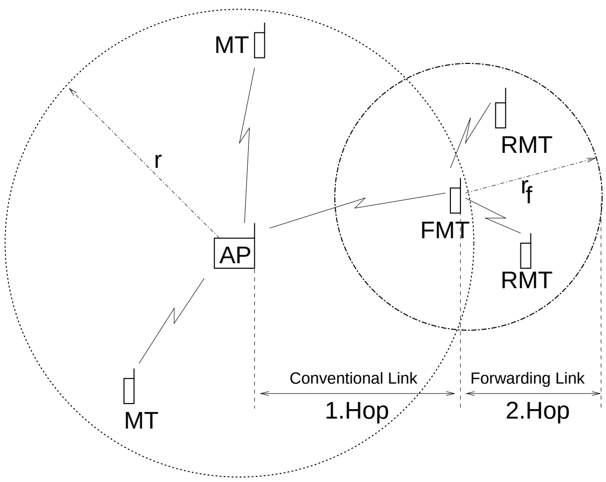

Fig. 1: Forwarding Scenario

A typical forwarding scenario is presented in Figure 1. It generally applies to outdoor and indoor/office environments.

The *Remote Mobile Terminal (RMT)* is an MT that cannot communicate directly with the AP on the *Conventional Link* (one-hop) but needs a forwarding link for two-hop communication. The term *Remote* differentiates it from a normal MT that is connected to the AP over the one-hop link. An MT associated to the AP via a one-hop link and located at the edge of the AP coverage area may perform the function of a forwarder and is thus named *Forward Mobile Terminal*. Since the edge of the AP coverage area depends on the PHY mode [4] used, a new dimension is introduced into the H/2 world by the FMT to further complement the service coverage area.

2 Forwarding in H/2

There are a number of possibilities to employ forwarding for the H/2 system. The concepts are sketched in Figure 2:

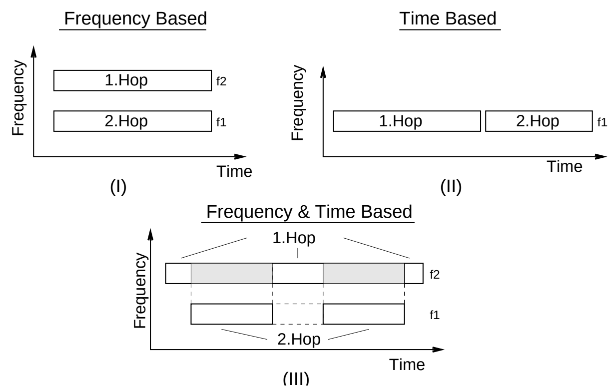

Fig. 2: Forwarding Concepts in Time and Frequency Domains

(I) One-hop links (first hop) and forwarding links (second hop) operate on different frequencies.

(II) The links operate on the same frequency but are separated in time on a time sharing basis.

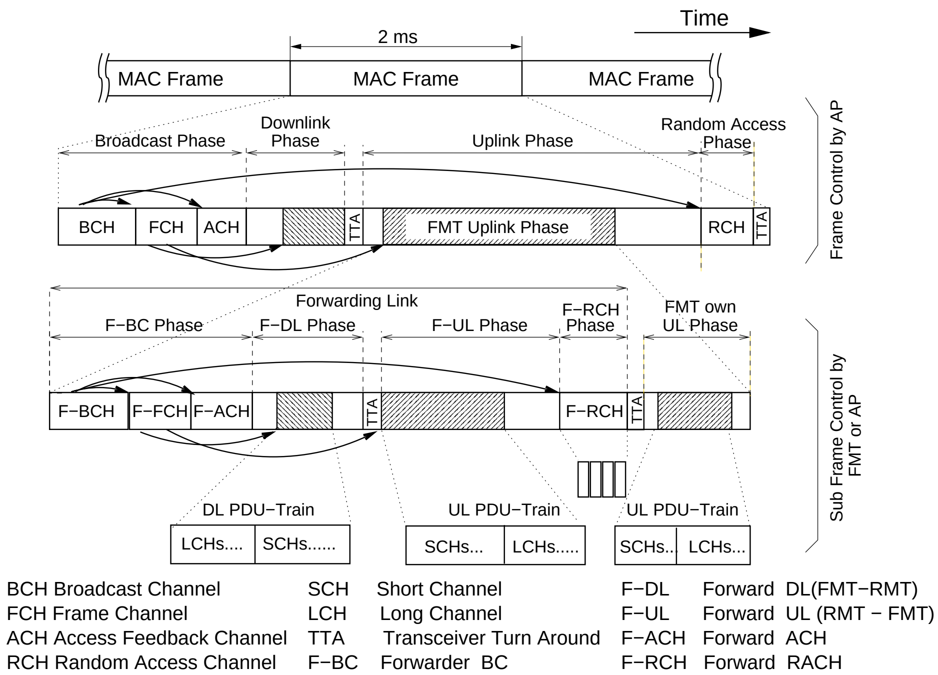

Fig. 3: H/2 MAC Frame Forwarding Sub Frame Structures

(III) A combination of (I) and (II). The FMT uses $f1$ for the second hop and $f2$ on a time sharing basis for the first hop.

FMTs may be fixed or mobile terminals. In the following the time based concept **(II)** is further explained and investigated, as it enables the entire system to use synchronised sub nets able to support well-defined *Quality of Service (QoS)* parameters. Due to the synchronised sub nets this concept needs only one transceiver per FMT and therefore keeps the hardware cost of an FMT low.

2.1 Medium Access Control Sub Frame

A possible implementation of the time shared forwarding concept without large modifications to the existing H/2 specifications [5] of MT and AP is shown in Figure 3.
The *H/2 MAC Sub Frame (SF)* shown at the bottom of Figure 3 is the key element of the new forwarding concept. The sub frame is generated by the FMT to communicate with the RMTs associated to it. The uplink phase capacity assigned to the FMT in the *H/2 MAC Frame* denoted as *MAC Frame (MF)* in this paper is exploited by the FMT to define the sub frame and to transmit its own uplink traffic if any.
The structure of the sub frame is similar to that of the MAC frame. The sub frame is nested into the MAC frame so that an MT can operate on both frames when working as an FMT. Further, an MT that is served temporarily as an RMT does only require little modifications of its protocol software (see below).
Since MTs synchronise to APs in the broadcast (BC) phase this phase has to be logically forwarded by the FMT to its associated RMTs. This phase is called *Forwarding Broadcast Phase (F-BC Phase)* in the sub frame.

Other phases of the sub frame appear to be exactly the same in structure as in the MAC frame. Thus during the *Forwarding Downlink (F-DL)* phase, the FMT transmits the data packets to one or more RMTs and receives uplink data from RMTs during the *Forwarding Uplink (F-UL)* phase.
The number of *Random Access Slots* in the *Forwarding Random Access CHannel (F-RCH)* may be smaller compared to the standard MAC frame, if the number of RMTs associated to an FMT is smaller than the number of MTs to an AP.
The sub frame is supervised by a scheduler located in the FMT. An FMT transmitting the sub frame will be received by the AP but only the FMT onw uplink phase of the sub frame is accepted by the AP whilst the other parts are ignored. The data flow in the FMT is handled in queues that decouple the data flow between conventional and forwarding links.

2.2 Design Aspects

The forwarding concept is aimed at offering an acceptable performance for throughput, delay and other QoS parameters.
The radio resources requested by an FMT will naturally be more than that of an MT, as the FMT generates *Resource Requests (RRs)* to the AP for the sub frame including F-BCH and F-RCH phases, its own uplink data and the data of the associated RMTs. This fact has to be reflected in the strategy adopted for the *Resource Grants (RGs)* in the AP.
In the FMT controlled concept further investigated, a standard AP is assumed to have no knowledge about an FMT and its sub frame used for forwarding.
This concept fits into the H/2 system with minor modification to the specifications: The MT has to search for the

BCH-Phase immediately after the end of the RCH phase even if there is a gap between RCH phase and the end of a MAC frame.

As the sub frame is controlled by the FMT it is acting for the RMTs like an AP, and for the AP both RMT as well as FMT are seen like MTs. The AP is not aware of the forwarding link. An RMT is connected to the AP via a two-hop link consuming approximately twice the MAC capacity of a one-hop link.

The uplink phase granted to the FMT is *re-scheduled* by the FMT into a sub frame and the FMT's uplink. The FMT has its own scheduler and other routines to handle the sub frame management. The resource grants received for the sub frame from the AP depend on the scheduling strategy in the AP.

The proposed forwarding scheme can be applied recursively. An RMT can also be used as a forwarder remote mobile terminal (FRMT) to connect a far remote terminal via serving FMT to the AP, and so forth. Besides point-to-point communication the forwarding concept seems to be especially beneficial for multicast and broadcast applications since no capacity appears to be wasted through the multihop transmission.

3 Traffic Performance

3.1 Scenario

To verify the FMT concept and to study the impact of FMTs on the QoS parameters transfer delay and system throughput simulation studies have been carried out.

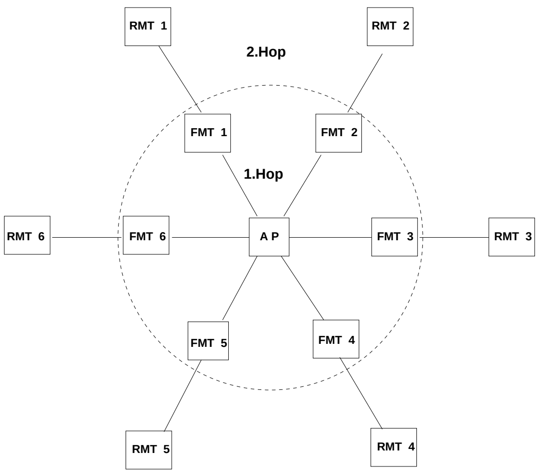

Fig. 4: Star Scenario

In the simulation scenario of Figure 4 some MTs were placed out of the range of the AP to act as RMTs that are associated with FMTs. The FMTs are associated with the AP directly. Both FMTs and RMTs are assumed to have one MAC connection each. Six FMTs and six RMTs are grouped together in the example scenario around the AP.

This scenario is referenced as *Star Scenario* in the following and is used as a reference scenario to investigate effects caused by a varying number of FMTs.

Parameter	1.Hop	2.Hop
No. RCHs	4	1
PhyMode LCH	16QAM3/4	64QAM3/4
PhyMode FCH	BPSK1/2	BPSK3/4
PhyMode SCH	BPSK1/2	BPSK3/4

Table 1: Overall Simulation Parameters

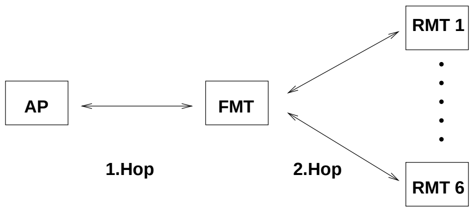

Fig. 5: Sub Net Scenario

Complementary, the scenario in Figure 5 is used to study the effects of an FMT serving a varying number of RMTs associated to a single FMT. This set of served RMTs is a *Sub Net Scenario* with respect to the serving FMT.

The simulation system can be loaded with a mix of constant bit rate, Poisson and video traffic sources. In the simulation results shown end-to-end user connections (i.e., connections between AP and RMT) loaded with Poisson traffic were used. Each user connection was loaded with the same amount of traffic, while no additional user connections from the user of the FMT to the AP were considered.

The most harmfull effect of the presented concept is the reduction of capacity for the whole system, as the data has to travel twice for two-hop connections. To keep the impact of forwarding on capacity as low as possible higher modulation schemes were used on the second hop. The number of RCH on the second hop was reduced to one to save additional capacity there. The resulting simulation parameters are summarized in Table 1.

3.2 Maximum Throughput

Maximum system throughput simulation studies have been performed for the star and the sub net scenario. The total system throughput is defined as the sum of data of all active connections per hop and per direction.

From the perspective of an RMT user in the star and sub net scenario, the available end-to-end throuhput for all users is displayed.

Figure 6 shows the simulation results for the star scenario for a varying number of FMTs and one RMT associated to each FMT. A set of one FMT and one RMT results in a maximum end-to-end (AP-to-RMT) throughput of approximately 14 Mbit/s using the PHY modes for LCH as given in Table 1. The maximum end-to-end throughput was derived from the calculated and simulated total system throughput, combining traffic on first and corresponding second hop as a single traffic flow. The calculations for the maximum

throughput taking the sub frames into account were done analog to [6] where the standard H/2 system is evaluated.
An increasing number of FMTs each serving a single RMT strongly decreases the capacity available for AP-to-RMT connections as more and more capacity is needed for organizing information introduced by the sub frames. A value of approximately 3.5 Mbit/s is reached for the example scenario of six FMT as depicted in Figure 4. The simulated results are supplemented with the calculated throughput for the proposed sub frame structure.

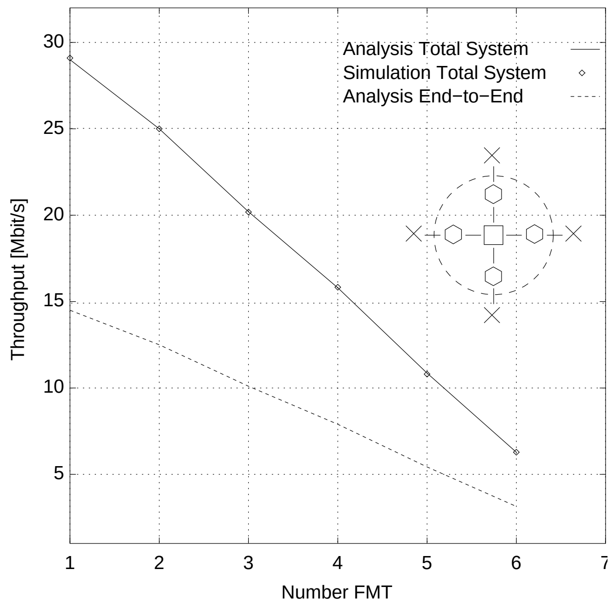

Fig. 6: Maximum Throughput vs. Number of FMTs in the Star Scenario

In Figure 7 the simulation for the sub net scenario is displayed, where the number of RMTs connected to a single FMT is varied. As expected, the increasing number of RMTs does not have the same dramatic effect observed in the star scenario with an increasing number of FMTs. This becomes obvious keeping in mind that the support of an additional sub frame needs much more resources (new F-BC, F-RCH, additional guardtimes for the whole subframe) than the support of an additional terminal in the sub frame (only small additional overhead in the F-FCH and small additional guardtimes for F-DL and F-UL are needed here). Compared to a system without FMTs [6] the number of RMTs to be supported in H/2 MAC Frame with comparable throughput is about half the number of MTs in a conventional setup, i.e., MTs supported in the first hop. This results reflects the fact that end-to-end data for an RMT has to be transmitted twice (to and from the FMT) and therefore needs about the double system capacity on MAC level.

3.3 Delay

In Figure 8 the complementary distribution function (CDF) of the delay for one-hop and two-hop forwarding links are shown. The CDF allows a complete understanding of the

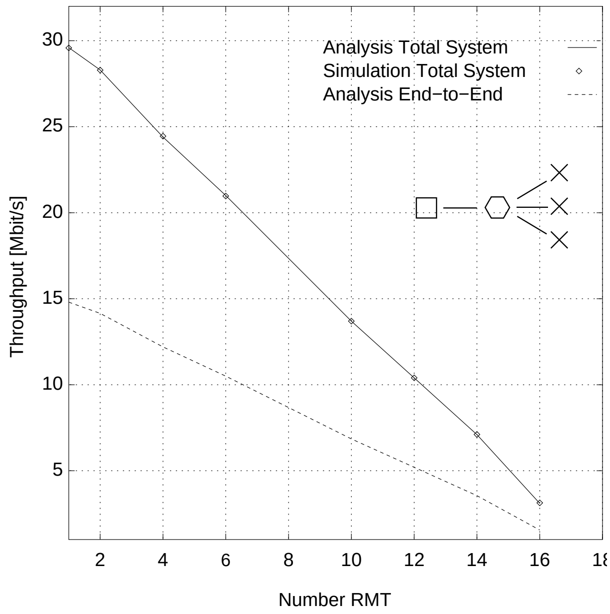

Fig. 7: Maximum Throughput vs. Number of RMTs in the Subnet Scenario

delay behavior since it gives the probability of a given delay time that can be guaranteed for a connection.

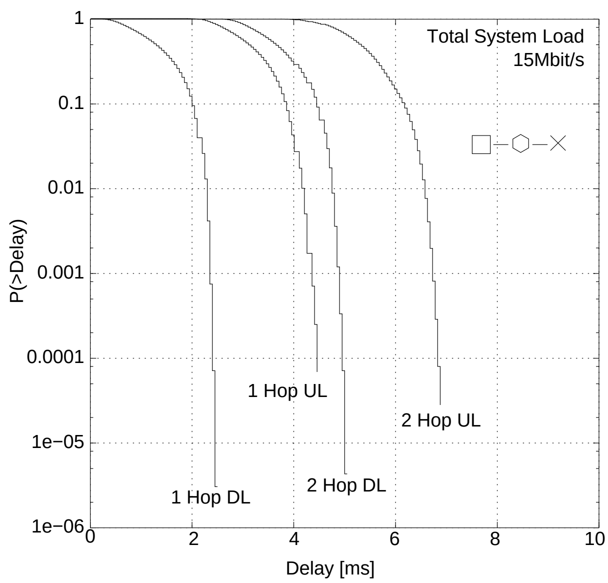

Fig. 8: CDF of Delay under Forwarding

An additional delay of a little more than 2 ms in uplink and downlink directions for the two-hop forwarding link is observed compared to the one-hop link.
In the downlink direction this is caused by the fact that the capacity for forwarding of a received downlink packet by the FMT is granted in the following MAC frame. As the sub frame is alway scheduled after the first hop downlink of the MAC frame the packet has to wait one complete MAC frame and the time between it was sent to the FMT and its offset to the transmission in the sub frame.

For similar reasons the uplink shows the same behaviour. In this case the position of the sub frame is scheduled before the first hop uplink to keep the end-to-end downlink delay as low as possible. Unfortunately the packet cannot be forwarded without delay, as first capacity has to be requested for this packet on the uplink to the AP.

4 Connectivity

Besides the impact on QoS and the system capacity in forwarding cases for the H/2 system this section discusses the size of the service area possible with FMTs in an unplanned system setup.

For these calculations the geometric settings are used as depicted in Figure 9 and Figure 11. The range of all H/2 entities (r, r_m) is normalised to 1. The variable d denotes the distance between RMT and the edge of the cell served by the AP.

An RMT is considered serveable if there is an FMT in service range of the AP and at the same time in range of the RMT, i.e., at least one FMT has to be in the intersection of the circles around AP and RMT. Inside the AP cell an equally distributed occurrence of possible FMTs is assumed. As result the service probability P_s is calculated.

In the indoor scenario the RMT is located in a corridor and will have access to the APs via an FMT only.

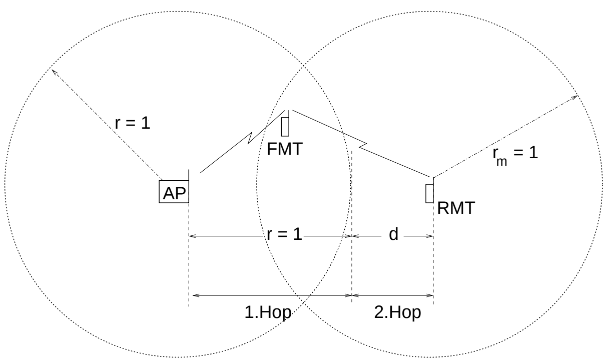

Fig. 9: Outdoor Scenario

Figure 10 shows the distance d in an outdoor scenario depending on the number of FMTs in the base cell where the service probability P_s is reached.

The number of FMTs in the serving area of the AP has to be high to insure service with the requested service probability. It has to be kept in mind that this high number of FMTs is not the number of active forwarders but of possible candidates.

For the indoor scenario as depicted in Figure 11 the situation is even worse (see Figure 12), as the RMT has entered a corridor (width: $2g = 0.1$) without service from the AP. Therefore a much higher number of possible FMTs is needed to reach the requested service probability.

This analysis is based on a worst case scenario where no positioning of FMTs has been assumed. If FMTs are placed suitably, the service probability of RMTs in given places

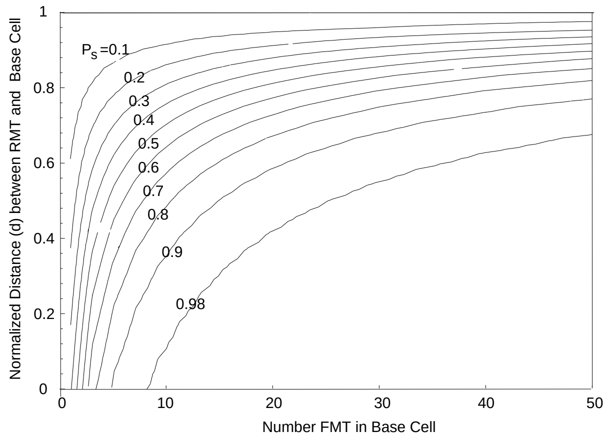

Fig. 10: Service Probability of RMTs in an Outdoor Scenario

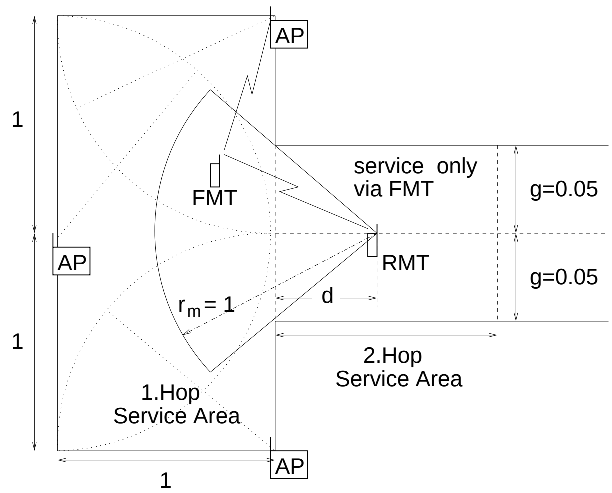

Fig. 11: Indoor Scenario

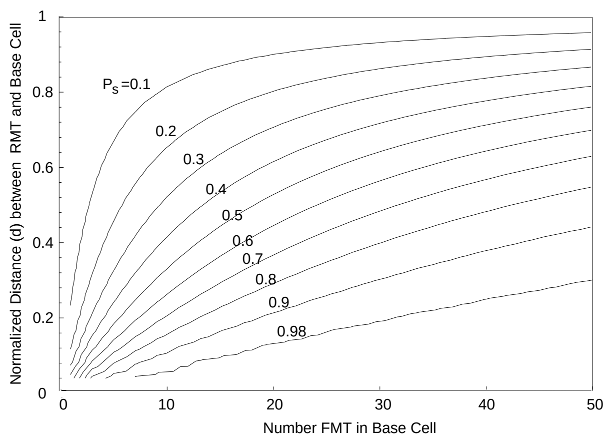

Fig. 12: Service Probability of RMTs for an Indoor Scenario

rises substantially. Positioning of FMTs may be organised by service provider.

5 Conclusions and Outlook

The forwarding concept presented for H/2 systems is able to extend the coverage of standard H/2 radio cells by employing a MAC sub frame structure generated by a new H/2 element called *Forward Mobile Terminal* (FMT) that provides a relay function for MTs outside the range of an H/2 AP.

The sub frame introduced applies time division multiplexing to alternating serve the first and second hop of a connection and is used in a way that synchonised sub nets are formed and only a single transceiver for the FMT is needed. The gain in communication range has to be paid with a degradation in system capacity. The modifications necessary to the existing H/2 standards to support this concept are kept to a minimum. The effects of the proposed concept onto Quality of Service has been shown in simulations.

A number of open question are still remaining. This includes enhanced scheduling strategies, the combination of a frequency and time based approach, the role of different modulation schemes and implemenation aspects.

The concept is especially advantageous in situations where the capacity of a cell served by an AP is not used-up by its MTs so that the remaining capacity is available for coverage extensions of the cell to connect RMTs.

6 References

[1] 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.

[2] Broadband Radio Access Networks (BRAN), "HIgh PErformance Radio Local Area Network - Type 2; System Overview," TR 101 683, ETSI, Oct. 1999.

[3] B. Walke, *Mobile Radio Networks*. New York, USA: Wiley & Sons Ltd., 1. ed., 1999.

[4] Broadband Radio Access Networks (BRAN), "HIPERLAN Type 2; Functional Specification; Part 2: Physical (PHY) layer," DTS/BRAN 101 475, ETSI, Apr. 2000.

[5] Broadband Radio Access Networks (BRAN), "HIPERLAN Type 2; Functional Specification; Data Link Control (DLC) Layer; Part 1: Basic Data Transport Functions," TS 101 761-1, ETSI, Apr. 2000.

[6] A. Kadelka, A. Hettich, S. Dick, "Performance Evaluation of the MAC Protocol of ETSI BRAN HiperLAN/2 Standard," in *Proc. of the European Wireless'99, ISBN 3-8007-2490-1*, (Munich, Germany), pp. 157–162, Oct. 1999.

7 Biographies

NORBERT ESSELING (es@comnets.rwth-aachen.de) received his Diploma in Electrical Engineering in 1994 from the Aachen University of Technology. From 1994 to 1996 he worked at T-Mobil, Bonn/Germany, in the Department for Signaling Specifications for the German D1-GSM-Network. During this time he was responsible for the ISUP specification. He was also involved in the GSM core net signaling specification and extensions (e.g., convergence GSM to fixed and satellite). In 1996 he joined the Chair for Communication Networks, where he is working towards his Ph.D. He participated in the ACTS Project SAMBA (wireless ATM) where he was involved in the implementation and integration of the SAMBA trail platform. Areas of research interest are protocols to support wireless broadband packet networks. Currently his focus lies on aspects extending the range of the HiperLAN/2 System.

HARBINDER SINGH VANDRA (hsv@comnets.rwth-aachen.de) worked at Aachen University of Technology participating in a scientific exchange program between Aachen University of Technology and the Indian Institute of Technology (IIT) Kanpur. After his stay in Aachen he went back in February 2000 to finish his Master Program at Kanpur. His research intrests during his visit in Germany focused on extending the HiperLAN/2 MAC Protocol and simulations of the HiperLAN/2 system.

BERNHARD WALKE (walke@comnets.rwth-aachen.de) received his Diploma and Doctors degree in 1965 and 1975, both from the Department of Electrical and Electronics Engineering, University of Stuttgart, FRG. From 1965 to 1983, he served at the AEG-TELEFUNKEN Research Institute at Ulm / FRG, and later as a department head in the AEG Division for High Frequency Techniques. 1983 he joined the Department of Electrical and Electronics Engineering at Fern University of Hagen as a full professor for Data Processing Techniques, where he established a research group of about 10 scientists. In 1990 Prof. Walke joined the Aachen University of Technology as a full professor for Communication Networks, and took over responsibility for lectures in Applied Computer Science, Data Communication Networks & Protocols, Traffic Theory for Performance Analysis, and for Mobile Radio Networks. His research group is working in mobile radio and fixed network services and protocols, queuing theory and stochastic simulation for performance evaluation, and design and formal specification of communication protocols. His newest book is 'Mobile Radio Networks - Networking and Protocols' (John Wiley & Sons, April 1999).