Extending the Range of HiperLAN/2 Cells in Infrastructure Mode using Forwarding Mobile Terminals

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Abstract

The basic idea of the presented new approach to extend the communication range of standard *HiperLAN/2 (H/2)* cells is to use a relay that supports in the time domain terminals outside the range of an H/2 access point. This concept is especially beneficial in indoor scenarios and hot spots when terminals are isolated from an access point and require access to a fixed infrastructure network. A new H/2 element called *Forward Mobile Terminal (FMT)* is employed that serves terminals out of range with a novel MAC sub frame structure. Besides the impact of FMTs on the achieved Quality of Service for the H/2 system the possible service area gain is analysed in this contribution.

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][4] when using the infrastructure mode as access to fixed networks for content provisioning.
A *Remote Mobile Terminal (RMT)* in this context is defined as an *Mobile Terminal (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 may perform the function of a forwarder and is thus named *Forward Mobile Terminal*.

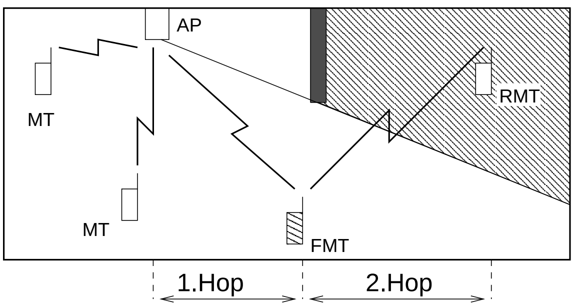

Fig. 1: Forwarding Scenario Indoor

In the indoor scenario as depicted in Figure 1 the area that is not covered by an AP is shaded. This area is not reached by the AP, as a wall attenuates the AP signals in a way that an MT (RMT) inside this area can not be reached. Therefore in the standard H/2 system the RMT does not have access to the fixed network which is connected to the AP only.

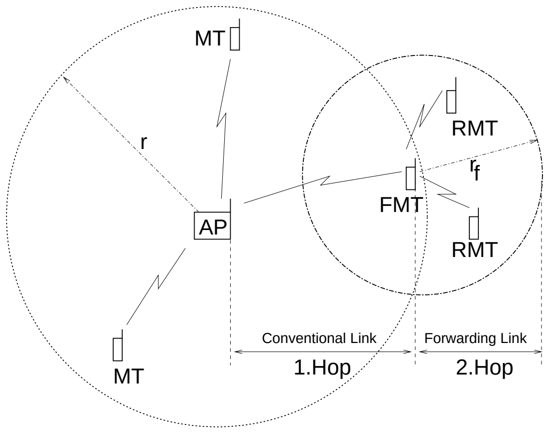

Fig. 2: Forwarding Scenario Outdoor

In the outdoor scenario as shown in Figure 2 an MT is not reached by the AP and is isolated.
The proposed concept is targeted on hot spot and indoor environments, where dynamically areas with no H/2 service have to be covered without big installation efforts.

2 Implementation of Forwarding in H/2

There are a number of possibilities to employ forwarding for the H/2 system:

(I) One-hop links (first hop) and forwarding links (second hop) operate on different frequencies. This requires two transceivers for the two frequencies.

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

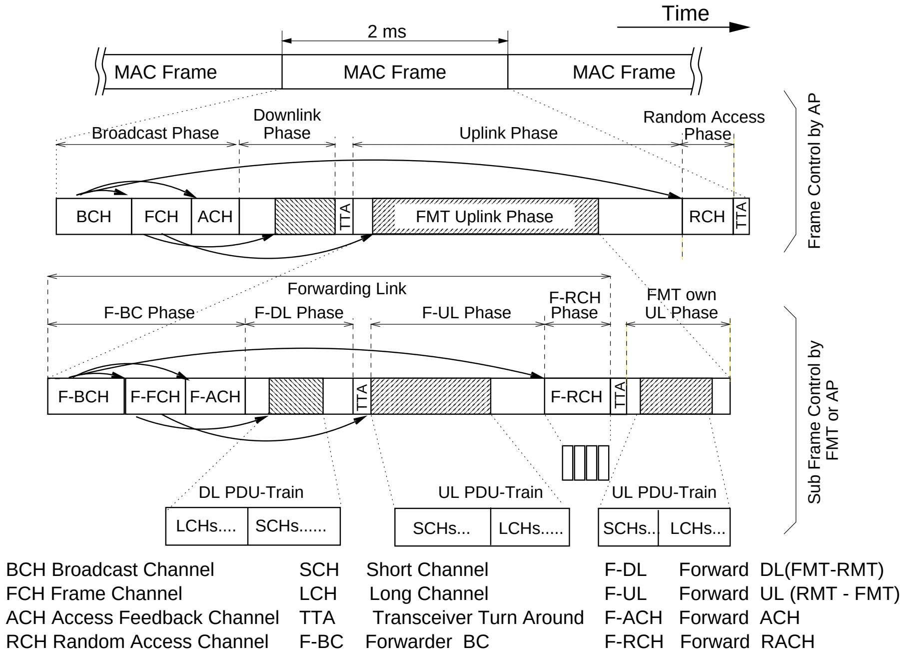

Fig. 3: H/2 MAC Frame including Forwarding Sub Frame Structures

(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. This allows the FMT to use only one transceiver for both links.

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 FMTs 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 basis for the implementation is the standard *H/2 MAC Frame* (MF). The upper part of Figure 3 shows the standard MF consisting of the *Broadcast Phase (BCH)* in which the AP announces the structure of the following MAC Frame to it's MTs. The BCH points to the beginning of the *Frame Channel Phase (FCH)*. The FCH contains information for each individual MT and connection where the respective transmission starts and the number of user information elements (*Short CHannels (SCH) and Long CHannels (LCH)*) are transferred either downlink or uplink. The FCH information is also called *Resource Grant (RG)*.

The *H/2 MAC Sub-Frame (SF)* shown at the bottom of Figure 3 is the key element of the new forwarding concept. The uplink phase capacity assigned to the FMT in the MAC Frame is exploited by the FMT to define the sub frame. The sub frame is generated by the FMT to communicate with the RMTs associated to it.

The structure of the sub frame is identical in structure to that of the MAC frame and is nested into the MAC frame so that an MT can operate on both frames when working as an FMT.

Since MTs synchronise to APs in the broadcast (BC) phase this phase is logically forwarded by the FMT to its associated RMTs. This phase is called *Forwarding Broadcast Phase (F-BC Phase)* in the sub frame.

The FMT transmits the data packets to one or more RMTs during the *Forwarding Downlink (F-DL)* phase and receives uplink data from RMTs during the *Forwarding Uplink (F-UL)* phase.

The *Forwarding Random Access CHannel (F-RCH)* has the same task as the RCH in the H/2 MF and allows RMTs to contact the FMT in case no dedicated resource was granted to an RMT and reserve capacity in the sub-frame. For the own data transmission of the FMT to the AP a further UL phase is introduced at the end of the sub frame.

The granted sub frame capacity by the AP is rescheduled by a scheduler in the FMT. An FMT transmitting the sub frame will be received by the AP but only parts conforming to the standard MF are accepted by the AP while other parts (i.e. sub frame components) are ignored.

2.2 Sub Frame Operation

The sub frame concept fits into the H/2 system with minor modification to the specifications: The MT has to search for the BCH phase (the F-BCH in case of an FMT) immediately after the end of the RCH phase (F-RCH) 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 the sub frame. 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.

3 Performance Analysis

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.

3.1 Simulation System

For the performance analysis of the concept a simulation system which was programmed entirely in the Specification and Description Language (SDL) was used and extended with parts concerning the Forwarding Mobile Terminal [6].

SDL was chosen as it is a standard way [7] of specifying protocols in modern telecommunication systems. The basic concept behind SDL is the description of the protocol with the help of finite state machines.

Besides the parts of the H/2 specifications partly specified in SDL the H/2-MAC, the F-MAC, the physical layer, the channel and a simulation control were added to form a complete simulation environment.

The concept of the simulation system provides a standardised access (gChannel) to the channel at a very low level which also allows the channel to be connected to other systems types and protocol stacks possibly operating in the same frequency range.

In Figure 4 the high level block specification of the simulation system is shown. It consists of the blocks: AP, MT, FMT, Channel and Simulation Control. Each of these high level blocks is sub divided into sub blocks containing specific layers of the H/2 protocol stack, namely the MAC, the *Radio Link Control (RLC)* the *Error Control (EC)* and the *Physical Layer (PHY)* [5] [8].

The *Simulation Control (SimControl)* provides the

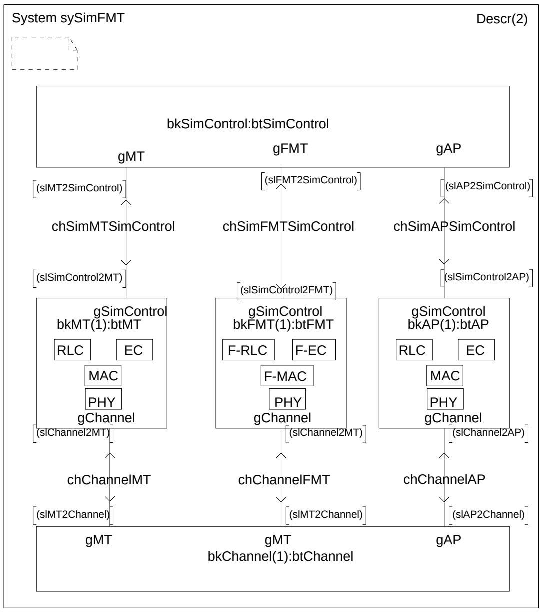

Fig. 4: H/2 SDL Simulation System

overall control of simulations and scenarios. During the development of the different parts of the simulation system the simulation control was used to emulate missing parts in a simplified way although using predefined interfaces. This approach also keeps the simulation system flexible.

For the analysis in this contribution the main focus was put onto the MAC, resp. F-MAC-Layer using the PHY layer and the channel. Simulation control, *Radio Link Control (RLC)* and *Error Control (EC)* were done by the SimControl.

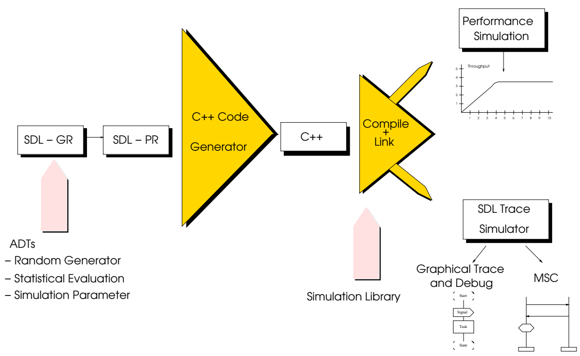

Fig. 5: From SDL to a running Simulation System

To form a running simulation a number of SDL Abstract Data Types (ADTs) as depicted in Figure 5 were added to the SDL specifications. These ADTs serve as random generators, statistical evaluation and simulation parameter handling. The resulting SDL code is then translated into C++-Code, compiled and linked with a simulation library. The result is either an executable machine code for trace and debugging purposes or a simulation code to get simulation results.

3.2 Scenario

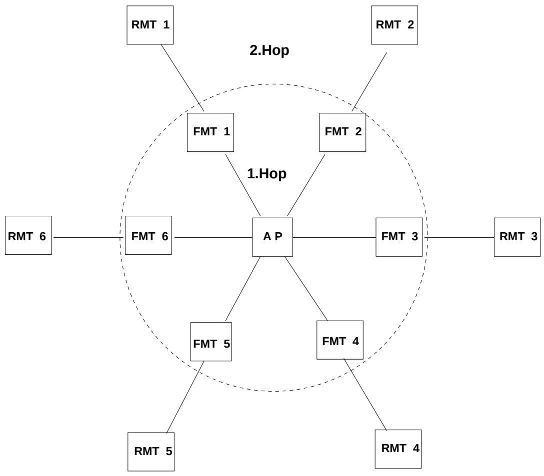

Fig. 6: Star Scenario

The reference scenario used in this paper is the *Star Scenario* as depicted in Figure 6. Some MTs were placed out of the range of the AP to act as RMTs that are associated to FMTs. The FMTs are associated to 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. In the simulations the number of FMTs each having attached an RMT is varied.

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

The most harmful effect of the presented concept was expected to be the reduction of capacity for the whole system, as the data has to transmitted twice for two-hop connections. Figure 7 shows a theoretical analysis of the maximum 2-hop end-to-end throughput and maximum system throughput (i.e. the sum of traffic on the first and second hop) parameterised with a small selection of different H/2 PhyMode [8] combinations for the second hop. The first hop was assumed to use parameters as displayed in Table 1. The maximum system throughput is referenced to ease comparison with the system load of standard H/2 systems [9].

The graphs start with nearly 30 Mbit/s (i.e. 15 Mbit/s for 2-hop end-to-end communication) and decrease significantly with the number of used FMTs. This decrease is caused by the increasing capacity needed for organising the sub frame(s). The remaining system capacity may be used either for 2-hop-communication, but also for 1-hop-communication. Pure 1-hop-communication with the same proportion of used PhyModes (e.g. 50% 16QAM3/4 and 50% 64QAM3/4 for LCH transfer) will show the same system throughput but the whole capacity is available end-to-end. This behaviour is caused by the fact that even if a FMT does not transfer data to RMTs it will need capacity to build empty sub frame, consisting of a F-BC- and F-RCH-Phase. The calculations for the maximum throughput taking the sub frames into account were done analog to [9] where the standard H/2 system was evaluated.

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

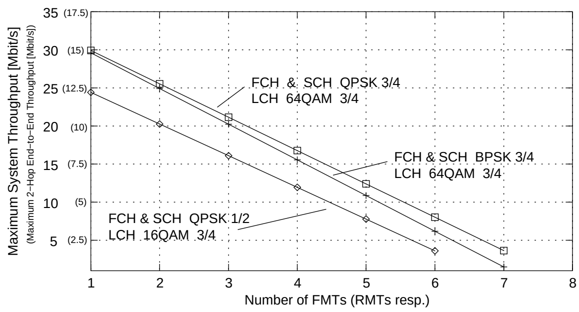

Fig. 7: Use of different H/2 PhyModes on the 2.Hop

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, as the number of MTs (i.e. RMTs) controlled by an FMT is lower then in the case of an AP. The parameters used for simulations in this contribution are summarized in Table 1.

3.3 Maximum Throughput

The total system user throughput is defined as the sum of user data of all active connections per hop and per direction. The system load is defined as the sum of the data going through the system. The 2-hop end-to-end throughput is the throughput available for a system with a given number of FMTs and an RMT user associated to each FMT.

Figure 8 shows the simulation results for the star scenario for a varying number of FMTs and one RMT associated to each FMT vs. the total system load.

A set of one FMT and one RMT results in a maximum total system throughput of approximately 28 Mbit/s using the PhyModes for LCH as given in Table 1. The maximum end-to-end throughput can be derived from the simulated total system throughput, combining traf-

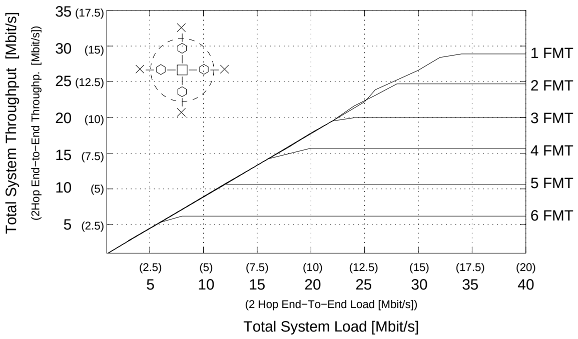

Fig. 8: Maximum System Throughput vs. System Load and Number of FMTs

fic on first and corresponding second hop as a single traffic flow (i.e. about 14 Mbit/s for 2-hop end-to-end traffic).

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 7 Mbit/s for the system throughput is reached for the example scenario of six FMT as depicted in Figure 6.

As long as the system is not overloaded a linear relationship between system load and throughput is observed. When the system reaches the point of maximum throughput it depends on the traffic characteristic, if the traffic can be carried or some parts of the load is deleted. This explains why there a no sharp turning points. If the system is heavily overloaded the maximum throughput can be observed. Packets are dropped when a maximum input queue length is exceeded.

3.4 Delay

Generally an additional mean delay of a little bit more than the duration of a H/2 MAC frame in downlink and uplink direction for the two-hop forwarding link is observed compared to the conventional one-hop communication [9].

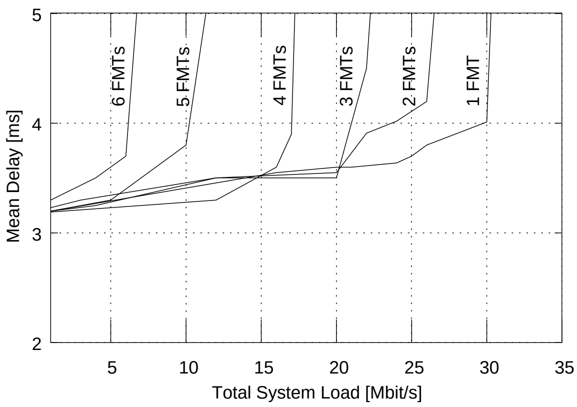

Fig. 9: Mean Downlink 2-Hop End-to-End Delay

In downlink direction the required time to transfer the H/2 data packets depends very much on the total system load of the system. Up to the maximum load possible the mean delay rises, as additional traffic will fill the H/2 MAC frame. The position in the frame will be shifted from the beginning of a frame to later parts in a frame and therefore higher the delay. This shift also effects the positioning of the sub frame. It has to be kept in mind that the second hop downlink will be transfered in the sub frame (i.e. in the uplink phase of the standard H/2 system). For this transmission capacity has to be requested from the AP, as it is done for a conventional uplink.

When the maximum transmission capacity of a scenario is reached the input queues start growing up to the point where packets have to be deleted. This is no stable point of operation and the resulting mean delay values are more or less meaningless. In a real system setup a *connection admission control* (CAC) will have to prevent the system from such heavy overload situations.

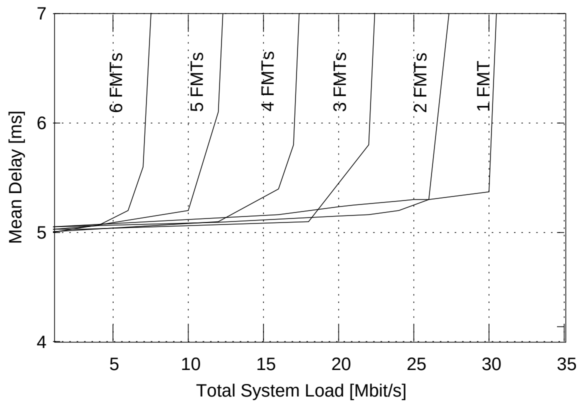

Fig. 10: Mean Uplink 2-Hop End-to-End Delay

In uplink direction a total mean delay of about 5 ms is observed. In standard scenarios a value of about 3 ms is observed [9]. The time of 3 ms on the conventional link reflects 2 ms to request the necessary uplink grant and 1 ms average waiting time for transmission. For the forwarding link an additional 2 ms has to be added for the sub frame capacity request. In uplink direction a similar dependency between system load and end-to-end delay is observed as for the downlink (i.e. raising delay because the frame is filled up more and more). But as the sub frame is already located in the uplink phase of a H/2 system the difference between high load and low load situations does not show such a strong effect. When the maximum system load is reached the system again enters an overload situation with the same consequences as already mentioned for the downlink.

4 Connectivity and Service Area Extension

Besides the impact on QoS and the system capacity this section discusses the size of the service area possible with FMTs in an unplanned and in the second part of the section with a planned system setup.
For these calculations the geometric settings are used as depicted in 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 serve-able if there is an FMT in service range of an 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.

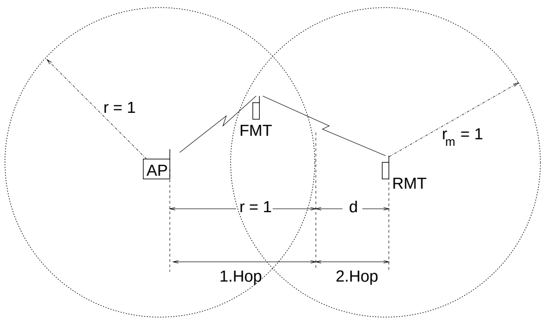

Fig. 11: Outdoor Scenario

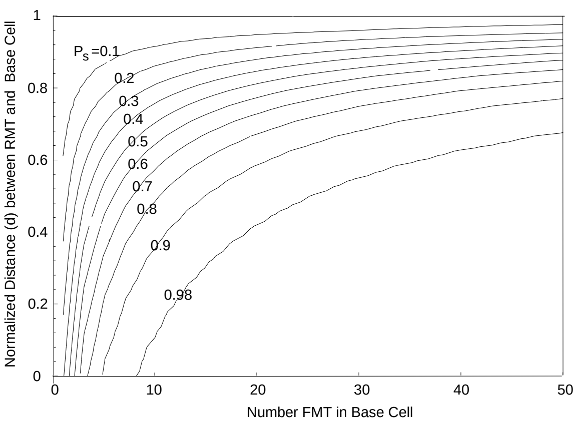

Fig. 12: Service Probability of RMTs in an Outdoor Scenario

Figure 12 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.
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 rises substantially. Positioning of FMTs may be organised by service provider. The advantage over conventional solutions is that no infrastructure is required.
In the following a planned system setup is analysed. The optimisation criterion is the maximum newly gained coverage area. For this setup the FMT are equally distributed along the edge of a cell served by an AP. Up to 3 FMTs the FMT coverage areas are not overlapping (see Figure 13).

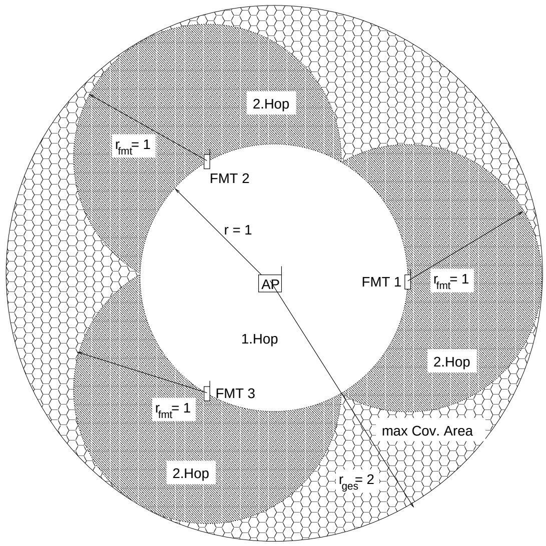

Fig. 13: Gained Area with 3 FMTs and Maximum Coverage Area

The effect of overlapping can be observed in Figure 14. Up to 3 FMT a linear increment of the newly gained service area is viewed. The maximum area which can be gained with 2-hop communication ($r = 2$) denotes to 4 times the area of a single cell (first hop, $r = 1$). Inside the newly gained coverage area 100% service probability is assumed.
With 2 FMTs already more than double the coverage area of a single cell or 55.4% of the overall maximum coverage area. Further 2 FMTs extend the area to 81.8% and with 6 FMTs already 90% are served. A further increasing number of FMTs only has a small effect onto the newly gained service area.
Keeping in mind the poor transmission capacity available when using 6 FMTs in a system setup a good trade-off between the capacity available for the system and the coverage area gain seems to lie between 2 and 4 FMTs in the system setup.
Depending on the preference of the service provider the system can be adjusted either going into large cov-

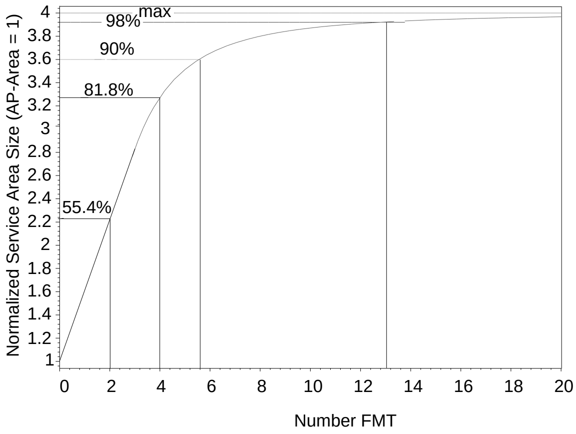

Fig. 14: Maximum Coverage Area vs. Number of FMTs

erage area or into high system throughput.
The analysis assumed a symmetrical coverage area and extension. This will not be the case in real environments. There will be a number of cases where it is required to cover floors or parts of a room. Such a setup will lead to a smaller number of FMTs necessary in the setup and leave more capacity for user data transfer.

5 Conclusions

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 *Access Point* (AP).
The sub frame introduced in this contribution applies time division multiplexing to alternating serve the first and second hop of a 2-hop connection and is used in a way that synchronised 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.
The gain in coverage area in a planned setup for cellular coverage has been analysed and results in an acceptable trade-off between the number of FMTs necessary to cover reasonable additional service area, the resulting overall system capacity and/or the end-to-end capacity available.
The proposed concept is especially beneficial in situations where no access for a H/2 user to a fixed H/2 infrastructure is available, but can be easily provided with an FMT which has access to an H/2 access point. This situation will be mainly the case in hot spot areas which in rarely used areas are not fully covered or in private indoor environments, where the owner of the equipment does not want to spent money for fixed infrastructure or is not able/willing to implement the this infrastructure.

6 Acknowledgment

This work was partly supported by the German research project COVERAGE (Cellular OFDM systems with extension points for increased transmission RAnGE) funded by the SIEMENS AG Munich/Bocholt.
The author would like to thank the members of the project for the valuable discussions.

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