On the Advantages of Direct Link Communication for HiperLAN/2 One-Hop and Multihop Ad Hoc Scenarios

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***Abstract*- The HiperLAN/2 (H/2) standard developed by the European Telecommunications Standards Institute (ETSI) provides high bit rate communication in the 5 GHz frequency band. Beside an infrastructure based networking mode, the profile for Home Environments follows the concept of a one-hop ad hoc network topology. Each so called single subnet is coordinated by a Central Controller whereby all H/2 home devices are capable of this function. In order to improve efficiency, Direct Link (DiL) communication among the home devices is recommended. In contrast to conventional Up- and Downlink operation, this mode is more robust in case of topology changes. The potentialities of DiL connectivity have been investigated in this paper not only for the well-known one-hop configuration, but also for the perspective of multihop ad hoc networks. Latter are made possible only by a *Multiple-Frequency Forwarding* technique presented as well.**

I. Introduction

The intention of ETSI to create the HiperLAN/2 standard was to offer wireless Internet, Intranet and Multimedia services to the user [1]. H/2 meets these requirements, it supports transmission rates of up to 54 Mbit/s applying the Orthogonal Frequency Division Multiplex (OFDM) modulation technique for the PHY layer. The Medium Access Control (MAC) is organized centrally and connection oriented using Time Division Multiple Access (TDMA/TDD) to provide Uplink, Downlink and Direct Link connections with specific Quality of Service (QoS) requirements [2]. All signaling functions, e.g. for establishment of user connections, are handled by the Radio Link Control (RLC) Protocol [3]. Additionally, the H/2 protocol stack contains convergence layers to adapt to higher protocol layers like ATM, Ethernet and IEEE 1394.

Beside the H/2 DLC basic specification designed for a cellular infrastructure, two profiles - for home and business applications – have been defined. For H/2 Home Environments (HE) the concept of a *one-hop* ad hoc network topology is followed to support operation in plug-and-play manner [4]. Per frequency channel the medium access of Wireless Terminals (WT) is coordinated by a Central Controller (CC), a terminal itself that has been assigned this function by the Dynamic CC Selection [5]. By a novel forwarding technique introduced in [6], single H/2 subnets can be interconnected to multihop ad hoc networks. The focus of this paper is set to the Direct Link communication that increases efficiency significantly and is the only possible mode of communication for *inter*-subnet links.

II. Direct Link Communication

A. *Unicast*

In infrastructure based networks, data are exchanged between two WTs via Uplink and Downlink. For ad hoc networks, however, Direct Link communication is preferred due to the self-organizing configuration. In case of a transfer of the CC functionality, a so-called CC Handover, for example, Uplink and Downlink connections need to be re-established whereas all Direct Links keep unchanged. Another advantage is the gain in capacity because a direct data transfer requires approximately half the resources than transmission to the CC and afterwards to a WT. Just the scheduling of transmission capacity and the corresponding signaling is taken over by the CC. Beyond saving capacity, DiL communication also improves the delay characteristics. Since there is no intermediate station, resource request and allocation delay is reduced. Thus, the DiL mode shows significant advantages regarding QoS especially for the use in Home Environments.

Considering the radio link, another benefit is given if there is a better direct radio connection between the involved WTs than to the CC. In this case, a less robust PHY mode may be chosen inducing a higher transmission rate. However, even the opposite is possible whereby in that case the CC may take over relay functionality resulting in conventional Uplink and Downlink conditions.

A detailed description of the signaling mechanism for DiL communication can be found in [4]. A WT with data pending for another WT indicates the required capacity to the CC by a Resource Request message sent in the Uplink. The CC responds using so called Resource Grants during the Broadcast Phase and informs the WTs about the capacity that has actually been allocated. The transmission of user data is then started in the indicated slots whereby the CC is not involved except it is acting as relay node or if it takes an active part in the DiL as sender or receiver itself. DiL is the only mode of communication that allows also duplex connection whereas Uplink (UL) and Downlink (DL) are simplex in any case. For the specific handling of duplex capacity, see [4].

B. *Multicast*

The objective of multicasting is to save capacity in the case of point-to-multipoint communication, meaning that a terminal delivers Protocol Data Units (PDU) not only to one destination, but to a group of users for applications like e.g. the distribution of video streams. The simplest, but most inefficient solution for this task is the approach of multiple unicast DiL connections. Another specific mode of transmission is provided by the HiperLAN/2 standard [4] reserving certain MAC IDs for groups of terminals. During the establishment of such Multicast Groups as well as by the Group Join Procedure for latter entering terminals, the set of participating WTs is negotiated. By identifying the group MAC ID in Resource Grants transmitted within the Broadcast Phase of each MAC Frame, all terminals belonging to the same group detect and receive multicast data concurrently.

Acknowledgements by receiving terminals are excluded due to the additional overhead of unicast feedback channels. Furthermore, there is the danger of inconsistencies if several confirmations for the same PDU could be received. Instead of the usual peer-to-peer ARQ mechanism, the Home Environment therefore envisions a repetition mode and a second level FEC based on Reed Solomon error correction for DiL multicast data transmission.

C. Performance Characteristics

1) *Simulation Scenario*: For the simulative evaluation of Direct Link communication in one-hop ad hoc configurations, a single room scenario, e.g. an exhibition hall, is considered whereby nine WTs communicate with each other either in direct way or via the CC that does not participate in communication except for signalling or relaying data, see Fig. 1. All WTs are line-of-sight inducing that the highest possible PHY mode 64 QAM ¾ can be set in. A similar scenario with WTs forming a ring topology has been presented in [7]. In this context the ring topology is based on DiL connectivity whereas the star topology is representative for UL & DL data transmission as known from fixed-infrastructure environments.

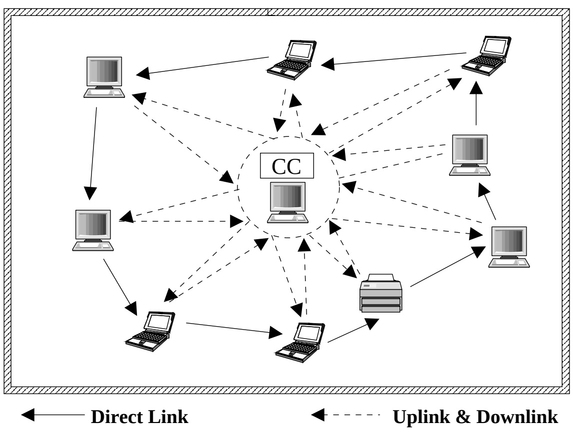

Fig. 1. One-hop Ad Hoc Simulation Scenario

2) *Throughput and Delay Analyses:* To get an impression of the ability of DiL in comparison to UL and DL, the parameters most relevant for QoS guarantee, the throughput and the delay were evaluated dependent on load and number of connections. Latter equals the number of involved terminals as per WT one connection is established.

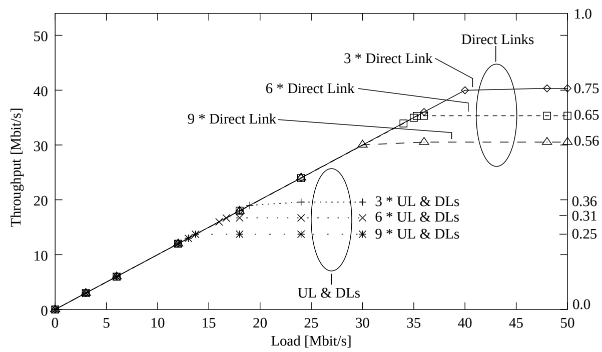

Fig. 2. Throughput vs. Load Characteristic

From Fig. 2, it can be seen that the saturation level for three Direct Links is reached with a throughput of about 40 Mbit/s whereas the combined Uplink and Downlink traffic is limited to half the throughput of only 20 Mbit/s. Another interesting effect is the influence of the number of connections that cannot be neglected at all. Owing to increased overhead for PDU train preambles, the available slots for user data per MAC Frame decrease with the number of connections. Per additional connection the throughput is reduced approximately for 3 % of the maximum possible throughput of 43 Mbit/s for a single connection.

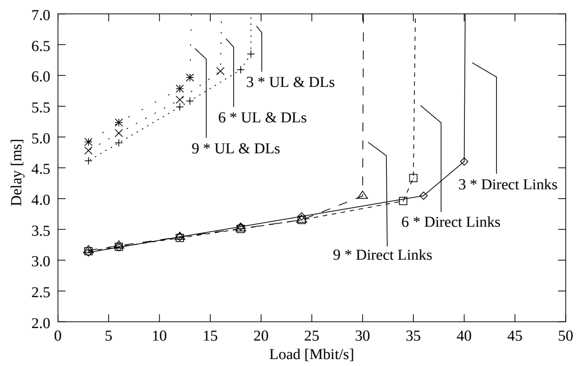

Fig. 3. Delay vs. Load Characteristic

For the delay, the corresponding effect is perceivable in Fig. 3. It is well recognizable that Direct Link communication does not only show benefits regarding throughput, but also for the delay. In case of UL & DL data transfer the delays of two hops sum up. Even, there is a correlation among UL and DL delay because the DL phase increases in length with the load carried. As the H/2 MAC Frame structure is designed such that the UL phase follows to DL and DiL phase, there is a direct interdependency of the DL length and the delay of UL PDUs relative to the beginning of the MAC Frame.

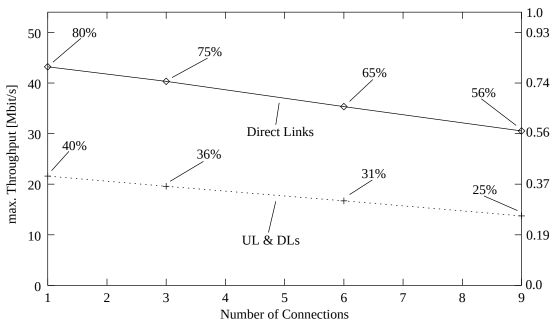

Fig. 4. Comparison of Direct Link and Up- & Downlink

In Fig. 4, an overview of the results is given. From this plot the maximum throughput can be derived versus the number of connections respectively involved WTs. Further, the percentage of the throughput related to the bit rate on PHY level of 54 Mbit/s is indicated.

III. MULTIHOP AD HOC ENVIRONMENTS

A. *Interconnection of Subnets by Multiple-Frequency Forwarding*

Today's stage of the Home Environment Extension considers only one-hop ad hoc networks whereby no communication across single subnets is specified. However, interconnection of subnets, meaning that WTs associated to any of the involved one-hop networks can communicate to each other, is planned for the second phase of standardization. Since each subnet decides about its operation frequency channel according to interference minimization based on the Dynamic Frequency Selection (DFS), a forwarding concept is required that considers overlapping networks on different frequency channels [6]. A corresponding scenario is shown in Fig. 5:

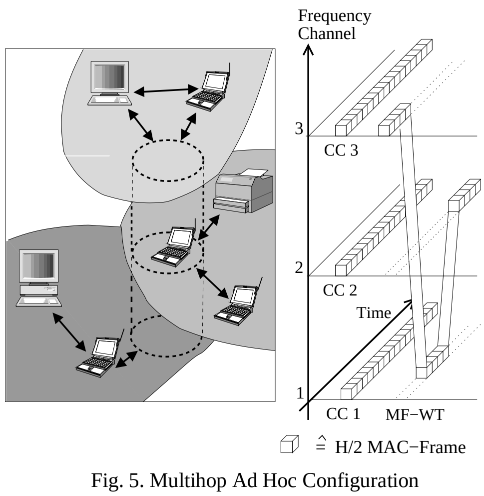

Fig. 5. Multihop Ad Hoc Configuration

The solution for *inter*-subnet forwarding is a novel approach that is founded on an intermitted presence of forwarding WTs, so-called *Multiple-Frequency Forwarders* (MF-WT) at each subnet [6]. This approach is very flexible and allows nearly all constellations of connecting *M* subnets by *N* forwarder nodes. Beside an additional buffer memory, *MF*-WTs only rely on the functions MT_Absence and MT_Alive, that are already covered by the RLC standard [3]. A terminal selected to be *MF*-WT, periodically withdraws from transmission for negotiated periods of $0 \leq$ *mt-absence-time* ≤ 63 MAC Frames. During these absence periods, it continues operation in a second or even third subnet as depicted in Fig. 5. Since an *MF*-WT has direct radio contact concurrently only to WTs of one subnet, it emulates the other subnets' destination WTs and caches all *inter*-subnet PDUs. For the data exchange across subnets, Direct Link is the only possible mode of transmission because common WTs need to be capable of forwarding. For such *MF*-WTs, it is not possible to send data in downlink or receive data in uplink direction inducing that these modes cannot be used at all.

Fig. 6 illustrates the operation of one (two) *MF*-WT(s) successfully associated to the CCs of two subnets in detail. The *MF*-WT is present periodically either for CC1 or CC2. To leave the current CC, for example CC1, it transmits the *RLC_MT_ABSENCE* message and, when it receives the acknowledgement, the radio connection to CC1 is intermitted and the absence period timer is started. After switching frequency, that is expected to last 1 ms [8], the *MF*-WT synchronizes to CC2. If the *MF*-WT awakes in subnet 2 earlier than expected, its presence is signalled by transmitting an *RLC_MT_ALIVE* message via the Random Channel (RCH). Otherwise, it is scheduled by the CC automatically and just starts transmission. To return to subnet 1 the MT_Absence procedure is executed again. This sequence is repeated continuously whereby symmetric and asymmetric periods may be selected according to the load situation.

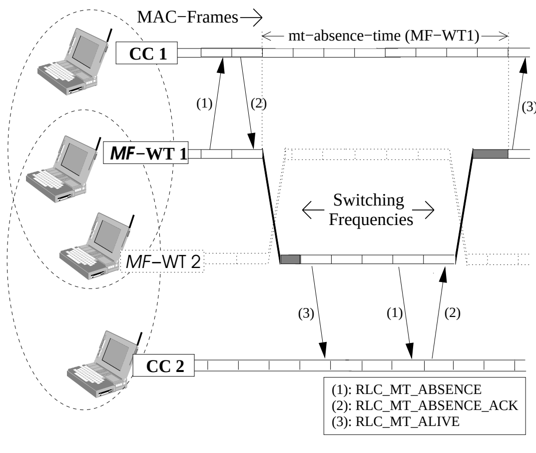

Fig. 6. *MF*-WT operation in subnet 1 & 2

As an *MF*-WT is only partially present in one subnet, the *inter*-subnet-throughput is limited to less than 44% of the maximum possible *intra*-subnet-throughput [6]. In case of several terminals located in the overlapping area of involved subnets, the **"Alternating Forwarders"** approach allows to enhance throughput and reduce delay. If, for example, two networks are coupled by **two** *MF*-WTs, as depicted in Fig. 6, the absence periods of both *MF*-WTs can be coordinated in the way that alternating one of the *MF*-WTs is available for one subnet. Thus, a nearly steady interconnection can be achieved. Only for frequency switching and synchronization no *MF*-WT is present at one subnet.

B. *Performance Characteristics*

1) *Simulation Scenario:* In order to evaluate DiL communication in multihop ad hoc environments under realistic conditions, event driven computer simulations have been performed. Two scenarios were considered dependent on the simulation focus. On one hand, a three room flat with nine wireless H/2 devices, see Fig. 7, was used to examine a two-subnet constellation. Under the given radio propagation situation, the subnets overlap in the central room where the terminals selected to be *MF*-WTs are located. On the other hand, a scenario consisting of four rooms with three established subnets was set up to value 3- and 4-hop connections with and without CC-relaying.

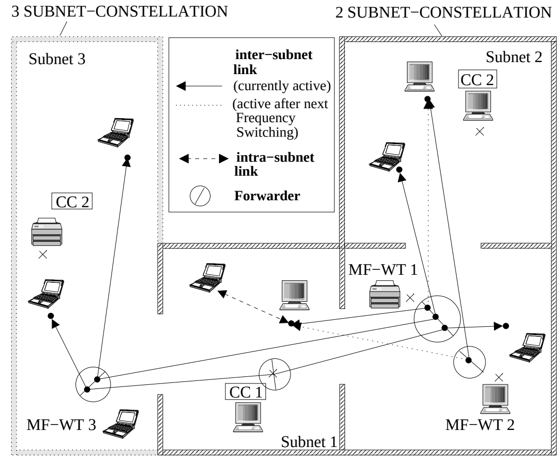

Fig. 7. Multihop Ad Hoc Simulation Scenario

Since most H/2 devices belonging to one subnet are line-of-sight or in low distance, the highest possible PHY mode 64 QAM ¾ can be applied for all DLC User Connections (DUC) with a low Packet Error Ratio. Per DUC various parameters, like unidirectional/bidirectional communication or different QoS requirements are adjustable. Load generators for Constant Bit Rate, MPEG video and Poisson traffic sources are available.

2) *Throughput and Delay Analyses:* The performance of *inter*-subnet Direct Links forwarded by a single *MF*-WT respectively two alternating *MF*-WTs was analyzed for unidirectional as well as for bidirectional Poisson traffic in comparison to the one-hop characteristic. Per *MF*-WT, the absence periods have been chosen symmetrically for both subnets. In Fig. 8, the maximum throughput as well as the delay characteristics are plot against the absence period length (mt-absence-time) given in the unit of MAC frames (2ms). The results are based on simulation series evaluating throughput and delay versus load and absence time. From the left plot, the upper throughput limitation can be derived for the two-forwarder constellation to be 38 Mbit/s whereas 20 Mbit/s are reached by a single *MF*-WT. Another interesting aspect is that no forwarding is possible for an absence time of three MAC frames and below. This fact is caused by the unavailability of MAC Frames for the *MF*-WT owing to frequency switching, synchronization as well as resource request and signaling overhead.

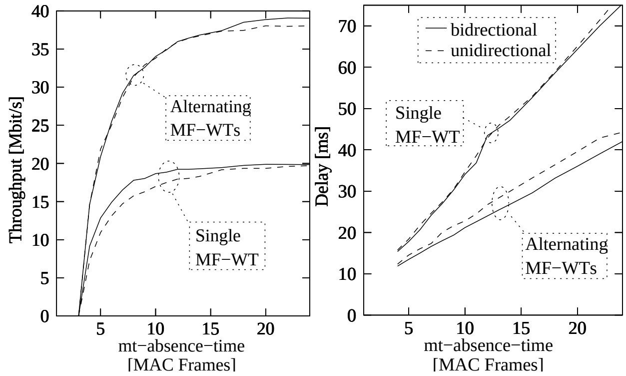

Fig. 8. Throughput and Delay versus Absence Time

In the right plot, the delay is presented for traffic loads close to, but excluding the saturation phase. Beyond the linear relation of delay to absence time, this diagram shows that the two-forwarder approach outperforms the single *MF*-WT not only for the throughput, but also regarding the delay.

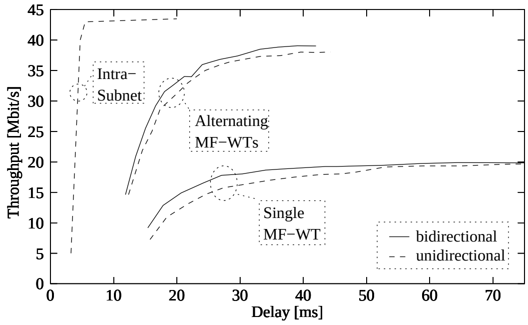

Fig. 9. Throughput versus Delay Plot

By combining the results to one plot, see Fig. 9, the set of possible operation points for single and two alternating forwarders can be identified as the areas below the curves. This representation shows a slight gain in delay and throughput for bidirectional compared to unidirectional traffic and, for sure, the convincing benefits of the “Alternating Forwarders” concept. Additionally, the plot includes the characteristics of an *intra*-subnet direct link as a reference. It is perceivable that with two forwarders in parallel the performance converges to the direct link capabilities in one-hop ad hoc scenarios.

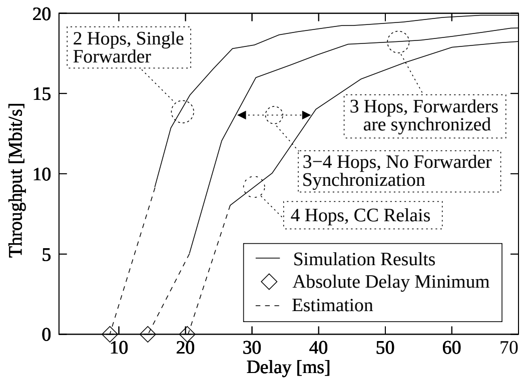

Fig. 10: Performance of Multihop Traffic

By extending the scenario for a third subnet, two further types of *inter*-subnet connections are worthy to note. WTs of subnet 2 and 3, i.e. the outside networks that are out of transmission range, can only reach each other via 3- or even 4-hop routes. If there is a perfect coordination of the *MF*-WTs connecting subnet 1 and 2 respectively subnet 1 and 3 in the way that both forwarders are present in subnet 1 concurrently, a forwarder-to-forwarder direct link can be established resulting in a 3-hop connection. Whenever only one of the *MF*-WTs is present in subnet 1, however, the only reasonable solution is to deliver the PDUs to the CC, that is expected to relay the data as soon as the other *MF*-WT returns. In Fig. 10, the performance characteristics of 2-hop up to 4-hop connections are compared in the form of throughput vs. delay curves. It turns out that especially the delay is affected by an additional hop.

IV. SUMMARY AND DISCUSSION OF SIMULATION RESULTS

In order to resume the investigations and to compare the DiL capability for one-hop and multihop constellations, Fig. 11 plots the maximum throughput as well as mean and minimum delay against the route length in hops. One curve parameter is the number of forwarders connecting two adjacent subnets, i.e. either a single or two alternating *MF*-WT(s). For the second parameter, the Absence Time, three characteristic cases are considered – a delay optimized value of 5 MAC frames, a throughput optimized value of 15 frames and 10 frames as a compromise.

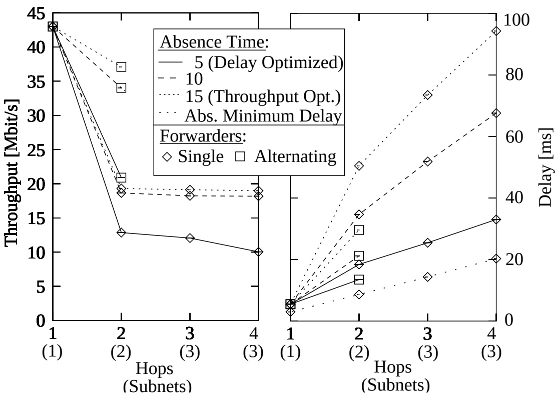

Fig. 11: Throughput & Delay vs. Route Length (Hops) & Subnets

From the graphs, shown in Fig. 11, it can be concluded that an *MF*-WT should adapt the absence time to QoS demands of the traffic mix it serves. In case of time-critical services, a low absence-time shows a good delay performance even for 3- and 4-hop routes whereas the throughput is significantly reduced.

Another interesting effect, that has to be explained, is the minor throughput decrease from 2- up to 4-hops. Considering the 3-hop scenario, for example, it can be found out that data from subnet 2 to 1 and from subnet 1 to 3 and vice versa are transferred in parallel inducing similar conditions as for 2-hop communication. A fifth hop, however, is expected to reduce *inter*-subnet throughput stronger. Corresponding simulations are currently in preparation.

V. CONCLUSIONS AND OUTLOOK

This paper gives an overview of Direct Link communication in HiperLAN/2 ad hoc networks. It covers the advantages of its use in currently available one-hop networks as well as the appliance for the novel concept of interconnected ad hoc subnets. By simulations the performance characteristics were investigated compared to Up- and Downlink data transmission in the single subnet scenario. For the multihop environment both the single and the alternating forwarder(s) approach were valued in a two-subnet constellation. Last but not least, 3- and 4-hop communication was examined based on a configuration of three subnets. The DiL proved to show best performance results. Future research will focus on DiL multicast communication that has to be extended on multihop configurations as well.

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