HiperLAN/2 Multihop Ad Hoc Communication by Multiple-Frequency Forwarding

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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 functionality. In order to overcome the restrictions of the one hop configuration, this paper presents a novel *multiple-frequency* forwarding technique enabling *inter*-subnet links and extending the one hop to a multihop ad hoc connectivity. Especially, the "Alternating Forwarder" approach, considering more than one forwarder terminal, achieves nearly continuous *inter*-subnet communication with convincing throughput and delay characteristics.

1. 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 protocol is organized centrally and connection oriented using Time Division Multiple Access (TDMA/TDD) to provide uplink, downlink and direct link connections with specific 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 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]. As an valuable supplement to the current standard, this paper presents a novel forwarding technique to interconnect single H/2 subnets to multihop ad hoc network configurations.

2. Multihop Ad Hoc Communication

Interconnection of subnets means that WTs associated to any of the involved subnets can communicate to each other. 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 subnets on different frequency channels [6].

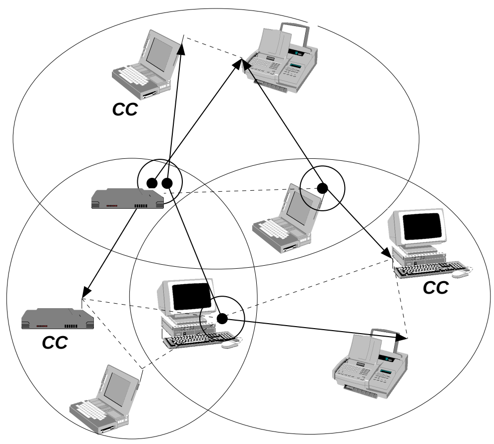

Fig. 1: Interconnection of Subnets

In **Fig. 1**, an example for a corresponding multihop network configuration consisting of three interconnected subnets is depicted. The WTs operating as *Multiple-frequency Forwarders* (*MF*-WT) are marked by circles. Though not displayed, constellations with *MF*-WTs connecting more than two subnets and connections spanning over more than three hops are conceivable, too.

H/2 multihop ad hoc connectivity covers several specific aspects to be solved. The major precondition is to add the forwarder functionality to each H/2 home device because the more terminals are *MF*-WT capable the more stable *inter*-subnet links can be guaranteed. An active *MF*-WT is required to be located in an area with two or more overlapping ad hoc LANs and to hold radio contact to all ad hoc LANs it connects. One solution could be to equip each WT with two transceivers enabling operation on two frequency channels in parallel. This approach, however, induces much higher prices, power consumption, dimensions etc. for H/2 devices. Another more efficient solution is a time & frequency division approach whereby the *MF*-WT operates on one frequency channel for negotiated time periods intermitted by operation on one or more other frequency channels. Further aspects to be solved are the coordination of *MF*-WTs to optimize throughput and delay as well as the reorganization in case of handovers and changing radio coverage [6].

3 *Multiple-Frequency* Forwarding

3.1 Required H/2 RLC Functions

With the MT_Absence function, the H/2 RLC standard [3] enables WTs to withdraw from communication and to perform tasks that cannot be executed in active transmission state, e.g. DFS measurements. In order to inform the CC that it is unavailable for a time interval of $0 \leq$ *mt-absence-time* ≤ 63 MAC Frames, the WT transmits the message *RLC_MT_ABSENCE*. Not until the CC responds with *RLC_MT_ABSENCE_ACK*, the WT changes to the absent state and the absence timer is started. The communication between WT and CC is continued immediately when the absence timer expires. MT_Absence is applied for the novel interconnection concept to facilitate WTs to hold connection to more than one CC.

The intention of the MT_Alive procedure is to check whether a CC and WT can communicate to each other. In the context of forwarding the MT_Alive function may be used to indicate the presence of an *MF*-WT to the CC by sending an *RLC_MT_ALIVE* message after switching and synchronization to the new frequency channel.

3.2 Forwarding Mechanism

The new *inter*-subnet forwarding approach is founded on an intermitted presence of forwarding WTs at each subnet to be interconnected. Therefore, the *MF*-WT periodically withdraws from transmission for a certain number of *mt-absence-time* MAC Frames by using the RLC functions MT_Absence and MT_Alive. 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.

The preconditions for active forwarding are the detection of neighbouring subnets and the *MF*-WT selection by the CC of one subnet based on frequency scanning and DFS measurement reports. When a WT has been assigned *MF*-functionality, it switches frequency and tries to associate to the neighbouring subnet. In the case association is successful, *inter*-subnet connections will be established. Otherwise, the forwarder activity is canceled.

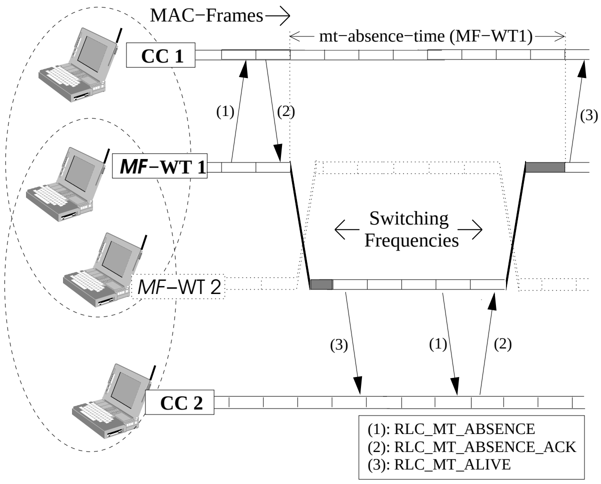

Fig. 2: *MF*-WT operation in subnet 1 & 2

Fig. 2 illustrates the operation of one (two) *MF*-WT(s) successfully associated to the CCs of two subnets. The *MF*-WT is present alternating either for CC1 or CC2. To leave the current CC, for example CC1, it transmits the *RLC_MT_ABSENCE* message containing the *mt-absence-time* parameter. When the *MF*-WT receives the acknowledgement, the radio connection to CC1 is intermitted and the absence period counter is started from the following MAC Frame on. After switching frequency, that is expected to last less than the upper limit of 1 ms [7], the Broadcast CHannel (BCH) transmitted by CC2 has to be detected and decoded to synchronize. The absence periods of the *MF*-WT in both subnets must be completely disjunct, meaning shortly after the absence period starts in subnet 1 it is recommended to end in subnet 2. For sure, a slight overlapping is possible. 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 and just starts transmission. To return to subnet 1 the MT_Absence procedure is executed again. This sequence is repeated periodically whereby both symmetric and asymmetric absence periods are adjustable according to the load situation.

3.3 Alternating Forwarder Technique

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 Forwarder" approach allows to enhance throughput explicitly depending on the number of terminals. If, for example, two networks are coupled by **two** *MF*-WTs, as depicted in **Fig. 2**, the absence and presence 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.

3.4 Buffering of *Inter*-Subnet PDUs

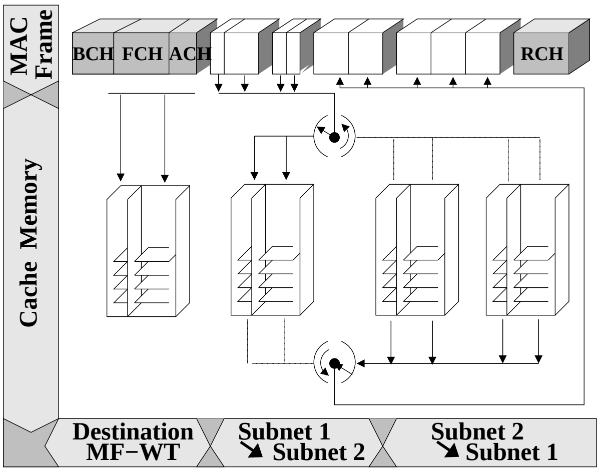

Fig. 3: Cache Memory for *Inter*-Subnet-DUCs

An *MF*-WT is required to emulate the other subnets' destination WTs and to buffer the Protocol Data Units (PDUs). The proposed memory structure is presented in **Fig. 3** as well as the read/write access to the buffer queues dependent on the current state of the *MF*-WT. For example, if the *MF*-WT is present for subnet 1, it receives and stores *inter*-subnet PDUs destined for subnet 2 and delivers buffered PDUs to subnet 1.

4. Performance Characteristics

4.1 Simulation Scenario

In order to evaluate *multiple-frequency* forwarding under realistic conditions, event driven computer simulations have been performed for the scenario of a three room flat with eleven wireless H/2 devices, see **Fig. 4**. Under the given radio propagation situation, two subnets have been established that overlap in the central room where the two terminals selected to be *MF*-WTs are located. Since most H/2 devices belonging to one subnet are line-of-sight, the highest possible PHY mode 64 QAM ¾ can be applied for all user connections with a low PER.

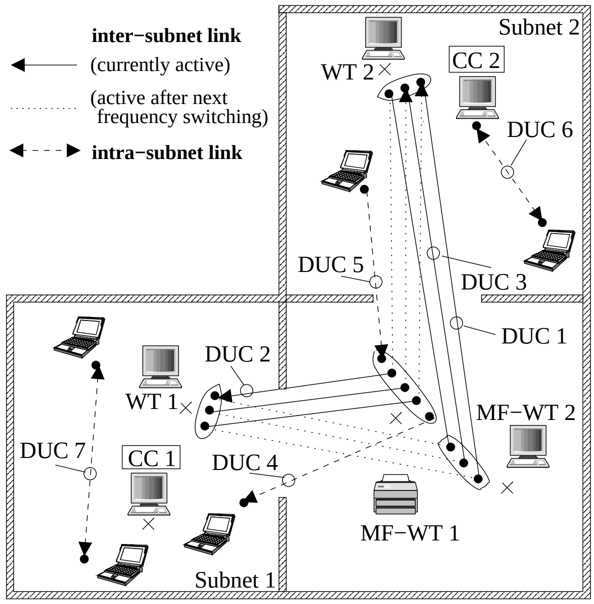

Fig. 4: Multihop Ad Hoc Simulation Scenario

Fig. 4 shows all DLC user connections (DUCs) that have been investigated dependent on the simulation focus. The DUCs 1-3, that are alternating served by *MF*-WT1 and *MF*-WT2, provide examinations of unidirectional and bidirectional *inter*-subnet traffic whereby different QoS requirements are adjustable. The influence of *intra*-subnet traffic involving the *MF*-WT is evaluated using DUC 4 & 5 whereas DUC 6 & 7 represent *intra*-subnet traffic without inclusion of an *MF*-WT.
Regarding QoS, a classification into *Best Effort Services, Differentiated Services* and *Integrated Services* is given in [8]. In order to model *Best Effort Services*, the simulation environment supports scalable Poisson traffic sources. *Differentiated Services* are represented by non-correlated MPEG video streams that have been derived from a trace file provided by [9] with a fixed interarrival time of 41.7 ms respectively 24 video frames per second.

4.2 Throughput and Delay Analyses

The *inter*-subnet performance capability of a single *MF*-WT in comparison to a constellation of two alternating *MF*-WTs was analysed for unidirectional as well as for bidirectional Poisson traffic. Per *MF*-WT the absence periods have been chosen symmetrically for both subnets. In **Fig. 5**, both maximum throughput and delay characteristics are plot against the absence period length (mt-alive-time) given in the unit of MAC Frames (2ms).

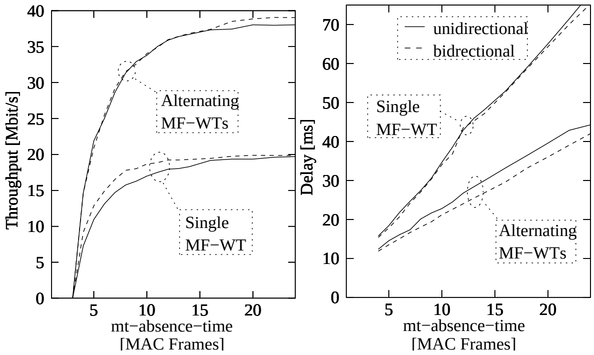

Fig. 5: Throughput & Delay vs. Absence Time

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 39 Mbit/s equivalent to 87 % of the highest possible *intra*-subnet traffic, that has been found out in [6] to be 45 Mbit/s. In case a single *MF*-WT is set in, the *inter*-subnet throughput reaches 20 Mbit/s or 44%. 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.

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. The system parameter most significant for *Integrated Services*, the lowest level of end-to-end delay, is reduced from 15 ms for the single *MF*-WT to 12 ms for the double *MF*-WT constellation.

By combining the results to one plot, see **Fig. 6**, the set of possible operation points for single and alternating forwarding can be identified as the area below the curves. This representation shows a slight gain in delay and throughput for bidirectional compared to unidirectional traffic, an effect that will be investigated in future studies in more detail.

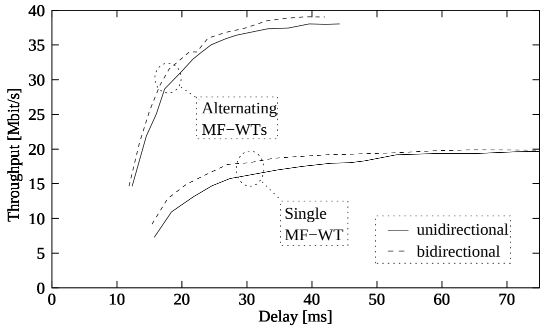

Fig. 6: Throughput versus Delay

Additionally, the convincing benefits of the Alternating Forwarder concept are well recognizable.

4.3 Drifting Forwarder Terminals

In [6], examinations regarding the phase shift between MAC Frames of non-synchronized subnets proved only minor effects. For sure, it is a legitimate question whether even *MF*-WTs, that are connecting the same subnets, could operate uncoordinatedly, too.

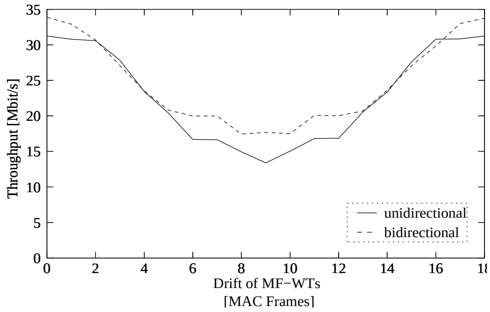

Fig. 7: Impact of MF-WT Drift on Throughput

As it can be seen from **Fig. 7,** the *inter*-subnet throughput varies periodically with an increasing drift of two *MF*-WTs to each other. Considering an absence time of 10 MAC Frames and one Frame lost by frequency switching, the period amounts to 18 Frames. Under the assumption that an *MF*-WT is able to detect other *MF*-WTs and stays passive until latter switch frequency, this simulation points to the requirement of forwarder coordination. In worst case both *MF*-WTs might have only the performance of a single one. However, in order to negotiate the alternating forwarder operation among the subnets, a temporary drift of the *MF*-WTs is reasonable.

4.4 QoS Support for *Inter*-Subnet Links

An essential advantage of H/2 against competing wireless LANs is the differentiation into mission-critical and non-mission-critical services [8], an ability that should also be provided by multihop configurations. In order to evaluate whether the *MF*-WT technique does support such QoS requirements, a higher prioritized MPEG stream was transmitted together with an scalable bidirectional Poisson load via the *inter*-subnet link.

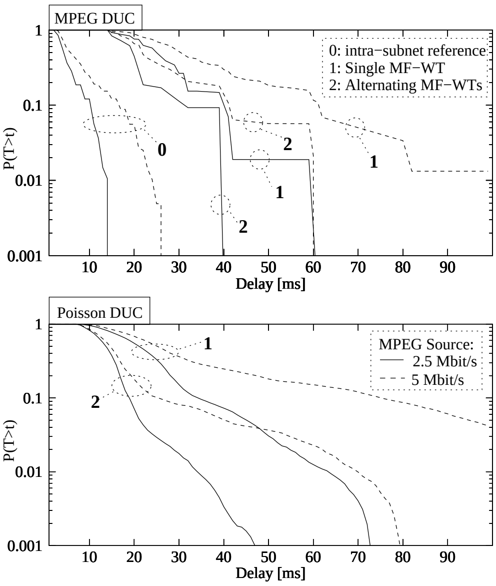

Fig. 8: CDF of the Packet Delay

From the results, presented in **Fig. 8**, it can be concluded that QoS is guarenteed. In the upper plot the Complementary Distribution Functions (CDF) of the delay are depicted for an offered *inter*-subnet traffic of 2.5 and 5 Mbit/s. As reference, the corresponding CDF characteristics are given for direct communication (0). It is conceivable that with 2.5 Mbit/s and Alternating *MF*-WTs (2) all QoS requirements are best fulfilled. The single MF-WT (1) approach shows acceptable results, too. Only 2.7 % of all transmitted PDUs exceed the 41.7 ms delay range. Under the given conditions, meaning an absence time of 6 MAC Frames, the 5 Mbit/s MPEG stream is only exchangable by Alternating *MF*-WTs at a reasonable outcome whereas the single forwarder is close to saturation. Additionally to the MPEG source, a 4 Mbit/s bidirectional Poisson load is transmitted whereby the lower plot presents the delay CDF for the same direction as of the MPEG stream. It is perceivable for all cases that the higher-prioritized MPEG traffic is treated significantly better than the Poisson traffic. However, even latter reaches satisfactory delay characteristics.

4.5 Serving *Inter*- and *Intra*-Subnet Traffic

Simulations were performed to evaluate the interdependences of *inter*-subnet and *intra*-subnet traffic served by one *MF*-WT concurrently. It turned out that *intra*-subnet traffic has more influence to an *inter*-subnet connection in the destination subnet owing to the resource request mechanism. Another interesting aspect is the fact that if the MF-WT serves DUCs in both subnets, these traffic streams not necessarily sum up because of the time-shared processing by the *MF*-WT, see also [6].

5 Conclusions and Outlook

The novel concept for interconnecting ad hoc subnets presented in this paper can be utilised in H/2 home devices without major changes. It extends the available one hop ad hoc topology to a multihop connectivity. By simulations the performance characteristics were investigated both for a single and for the Alternating Forwarder approach. The forwarding technique proved to be well applicable. The future research will focus on optimization and coordination of *Multiple-frequency* Forwarders.

6 Literature

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