A Concept for Interconnecting HiperLAN/2 Ad Hoc Subnets Operating on Different Frequency Channels

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Abstract

With the Home Environment Extension, the HiperLAN Type 2 (H/2) standard developed by the European Telecommunications Standards Institute (ETSI) provides a profile that follows the concept of a one hop ad hoc network topology. Such a so called single subnet is coordinated by a Central Controller whereby all H/2 Home Devices are able to take over this functionality. In order to allow communication not only within one subnet, but also for terminals operating in neighbouring subnets, this paper presents a forwarding technique enabling *inter*-subnet-connections and extending the one hop to a multihop connectivity.

1 Introduction

1.1 HiperLAN/2

The intention of the ETSI project BRAN (Broadband Radio Access Networks), that created the HiperLAN/2 standard, was to provide 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) protocol is organized centrally and connection oriented so that for every MAC Frame dynamically a defined capacity can be allocated to a user [2]. Based on time division multiple access (TDMA/TDD) uplink, downlink and direct link user connections are available [3] whereby specific QoS requirements can be supported for each connection. All signaling functions, e.g. for establishment of user connections, are handled by the Radio Link Control (RLC) Protocol [4]. Additionally, for the adaptation of the service requirements of higher layers, the H/2 protocoll stack contains common part convergence layers for packet based [5] and cell based data transmission and service specific convergence layers for Ethernet, IEEE 1394, ATM and UMTS.

1.2 Home Environment Extension - Ad Hoc Networking

Beside the infrastructure operation mode that is considered for the specification of the DLC basic functions, the communication between home devices including the support of IEEE 1394 is another objective of H/2. Therefore, the Home Environment Extension (HEE) has been developed. In contrast to the DLC basic specification designed for a cellular infrastructure, a one hop ad hoc network configuration has been chosen for the H/2 HEE to allow an operation in plug-and-play manner [6]. Per frequency channel the medium access of the Wireless Terminals (WT) is coordinated by a Central Controller (CC) that is a terminal itself. The CC functionality is supported by all H/2 Home Devices (H/2 HD) [7].
This paper describes a novel concept to combine HiperLAN/2 ad hoc networks, so called subnets, by providing *inter*-subnet connections. Therefore, WTs located in the overlapping radio areas are selected to take over forwarder operation. Each of these forwarding WTs is present alternating at the subnets to be interconnected until a forwarder handover becomes necessary or the *inter*-subnet link is released. The concrete realization is based on H/2 RLC functions already specified. Only minor changes regarding signaling aspects will be of use to fully achieve H/2 multihop ad hoc connectivity.

2 Interconnection of Subnets

In order to supply larger areas than covered by a single H/2 subnet, several H/2 networks need to be linked to one logical radio network. Such an interconnection of subnets has to ensure that WTs located at any position within the group of subnets can communicate to each other. The combination of subnets can be solved in different ways - either based on wireless solutions or using wired infrastructure like Ethernet or IEEE 1394. The wired interconnection distinguishes from well known base station oriented systems in that the access to the fixed network can also be taken over by WTs and is not restricted to the CC. Full **multihop ad hoc** connectivity and communication, however, is only achievable by wireless connections among the subnets. The subnets are each coordinated by an own CC that has been

assigned by the CC Selection algorithm presented in [8]. In order to guarantee the best possible interference situation for all terminals in a subnet, the Dynamic Frequency Selection (DFS) prevents neighbouring networks from using the same frequency channel. This implies a forwarder technique that considers overlapping subnets operating on different frequency channels (*Multiple-frequency Forwarding*).
A complementary concept – the forwarding on the same frequency channel – is set in to extend the range of infrastructure based networks [9]. Some additional information about H/2 multihop ad hoc networking and clustering can be found in [10].

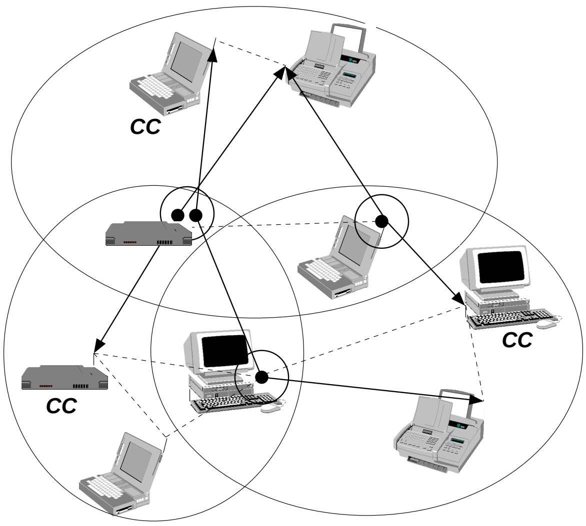

Fig. 1: Interconnection of Subnets

An example for a multihop ad hoc network configuration consisting of three interconnected subnets is depicted in **Fig. 1**. The established connections are represented whereby thick solid lines mean *inter*-subnet connections among WTs belonging to separate subnets, thin dashed lines, however, represent the *intra*-subnet traffic. Each *Multiple-frequency Forwarder* Wireless Terminals (*MF*-WT) is marked by a circle. This figure only considers *MF*-WTs between two subnets and connections spanning in maximum over three hops, respectively two *MF*-WTs. However, constellations with *MF*-WTs connecting three and more subnets are also conceivable.
Combining H/2 ad hoc subnets is a complex problem covering several specific aspects to be solved. The major precondition is to add the forwarder functionality to each H/2 HD 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, dimension etc. for H/2 HDs. Another more efficient solution is the time & frequency division approach, meaning each *MF*-WT operates on one frequency channel for negotiated time intervals of several MAC Frames intermitted by operation on one or more other frequency channels. Therefore, a cache memory is necessary for each *MF*-WT to store all data to be transferred from one subnet to another subnet until delivery. Further aspects to be solved for *MF*-WTs are mobility related handovers, the reorganization in case of changing radio coverage, and the coordination to maximize the *inter*-subnet throughput. Moreover, the influence of WT handovers and CC handovers, i.e. the transfer of CC functionality from one H/2 device to another [11], are to be investigated.

3 Wireless Terminals in *Multiple-Frequency* Forwarder Operation Mode

3.1 Concept

The new *inter*-subnet forwarding approach is based on an intermitted presence of a forwarding Wireless Terminal (*MF*-WT) at each interconnected subnet. Therefore, the RLC functions MT_Absence and MT_Alive are used in a slight different way to their original appliance. Since an *MF*-WT does only have direct radio contact to WTs of one subnet, it emulates the other subnets' destination WTs and caches all *inter*-subnet PDUs. Applying the “alternating forwarder” technique, presented in section 3.4, in addition, a nearly steady *inter*-subnet connectivity can be provided. One major advantage of this concept is that no significant changes of the H/2 standard are required. At most, some RLC signaling functions for coordination of the forwarding WTs are useful.

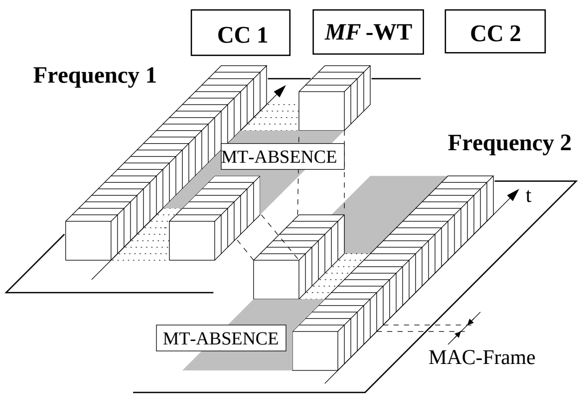

Fig. 2: *Multiple-frequency Forwarder* WT

An overview of the time and frequency coupling mechanism applied for an *MF*-WT is presented in **Fig. 2**. This figure depicts three involved devices - the CC of a subnet operating on frequency channel 1 (CC1), the CC of a second subnet operating on another frequency channel 2 (CC2), and the *MF*-WT being present on both channels alternating for separated time windows. The *MF*-WT first is synchronized to CC1. After a certain number of MAC Frames it changes into absent mode by executing the H/2 RLC MT_Absence function. From the point of view of CC1 it will stay in absent mode until wake up after a predefined time given in the unit of MAC Frames. Meanwhile, the *MF*-WT switches to frequency channel 2 and synchronizes to CC2. From the point of view of CC2 the *MF*-WT has been in absent mode up to now. It just turns to active mode and communicates for a defined number of MAC Frames to CC2 as normal WT. After this period it signals again a change to absent mode to CC2 and switches back to frequency channel 1 to awake right in time for CC1. This procedure is repeated continously and not stopped until the WT hands over forwarding functionality.

3.2 Required H/2 RLC Functions

3.2.1 MT_Absence

With MT_Absence an RLC procedure is given by the H/2 standard [4] that enables WTs to withdraw from communication and to perform tasks that cannot be executed in active transmission state, like for example Dynamic Frequency Selection (DFS) measurements. The WT informs the CC by the message *RLC_MT_ABSENCE* that it is unavailable for a preset time interval of 0 ≤ *mt-absence-time* ≤ 63 MAC Frames. Not until the CC responds with *RLC_MT_ABSENCE_ACK*, the WT changes to the absent state and the absence timer is started. With the expiration of the absence timer the communication between WT and CC is continued immediately. In case there are no data for the WT to transfer it executes the MT_Alive procedure, introduced in the following section 3.2.2.

MT_Absence is a core H/2 function intended to be applied for the novel interconnection concept. By this procedure a WT operating as forwarder can withdraw from communication to one CC and continue this communication after a predefined period. In the meantime the WT is free to perform any algorithm, even to switch to another frequency and to communicate with the second CC.

3.2.2 MT_Alive

By execution of the MT_Alive procedure a WT or a CC check whether they can communicate to each other [4]. The CC can control the state of association of a WT by sending the *RLC_MT_ALIVE_REQUEST* message. If this message is confirmed by the WT responding with *RLC_MT_ALIVE*, the WT remains associated. Otherwise, the signaling message is repeated by the CC expecting *RLC_MT_ALIVE_RE-QUEST_ACK* as answer from the WT. In case the WT does not respond again it is implicitely disassociated. A WT being in absent state gets active by sending an *RLC_MT_ALIVE* signal.

The MT_Alive function can be used for the forwarding concept in the way that the *MF*-WT may send *RLC_MT_ALIVE* to the current CC after switching to its frequency channel.

3.3 Forwarding Algorithm in Detail

Each WT participating in an H/2 ad hoc subnet is intended to perform frequency scanning and DFS measurements from time to time and to report the results to its CC. Based on the WT reports a CC is able to detect neighbouring ad hoc subnets and to select Forwarder WTs (*MF*-WT) to interconnect the subnets. Every *MF*-WT is permitted to periodically withdraw from transmission for a certain number of MAC Frames, the so called *mt-absence-time*. Within these absence periods a currently assigned *MF*-WT switches frequency and tries to associate to the neighbouring subnet. If the association timing requirements cannot be fulfilled, the *MF*-WT may also start the RLC Power Saving procedure that allows WTs to be absent for longer periods called *sleep intervals*. However, this function is less flexible than the MT_Absence and therefore only applicable for the association phase, but no alternative for forwarding user data. In the case association is successful *inter*-subnet connections can be established. Otherwise, the forwarder activity is canceled.

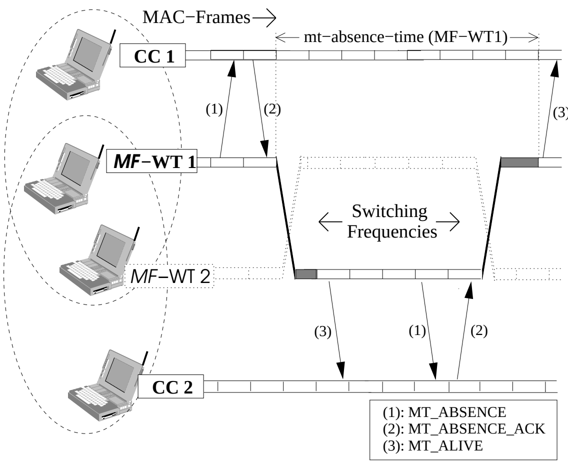

Fig. 3: One respectively two *MF*-WT(s) operating alternating in subnet 1 & 2

Fig. 3 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 [12] dependent on the implementation, 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 respectively CC1 the MT_Absence procedure is executed again. This sequence is repeated periodically whereby both symmetric and asymmetric absence periods are adjustable according to the traffic conditions.

3.4 Alternating Forwarding Technique

Since 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, see also section 4.2. In case several terminals are located in the overlapping area of interconnected subnets the ‘‘alternating forwarding” approach allows to enhance throughput and reduce forwarding overhead explicitly depending on the number of involved terminals. If, for example, two networks are coupled by **two** *MF*-WTs as depicted in Fig. 3, 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 at the frequency switching and synchronization phases no *MF*-WT is present at one subnet. The number of *MF*-WTs can be adapted by an intelligent coordination depending on the current load situation.

3.5 Cache Memory for Buffering Inter-Subnet PDUs

Since an *MF*-WT cannot be present at both subnets at the same time, it is required to emulate the other subnet's destination WTs, e.g. for observing ARQ delays etc., and to cache the Protocol Data Units (PDUs). This caching and the proposed memory structure is presented in **Fig. 4**. Beside the buffers for PDUs addressed for and generated by the *MF*-WT itself, buffers for all *inter*-subnet DLC User Connections (DUC) identified by so called DLC Connection Identifiers (DLCC ID) are needed. Per DUC separate cache memories for Long CHannel (LCH) and Short CHannel (SCH) PDUs are required.

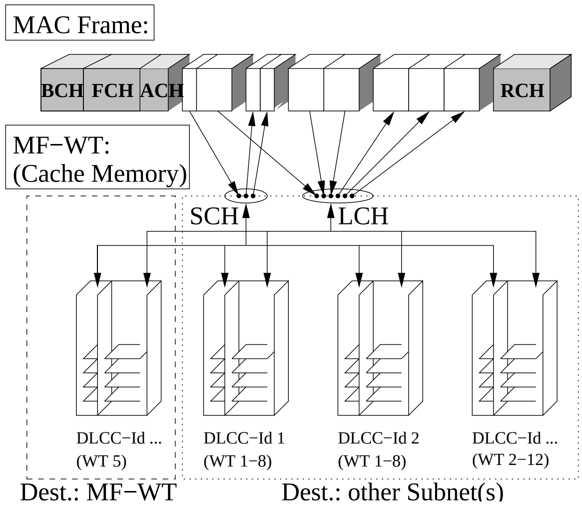

Fig. 4: Cache Memory for *Inter*-Subnet-DUCs

4. Performance Characteristics

4.1 Simulation Scenario

In order to evaluate *multiple-frequency* forwarding under realistic conditions, event driven computer simulations have been performed. The scenario that has been taken models a three room flat with ten wireless H/2 devices in total as presented in **Fig. 5**. Two subnets have been established on two different frequency channels considering the radio propagation situation. Except the terminal selected to be *MF*-WT, that is located in the central room, the subnets are restricted to the side rooms. Since the 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. The signaling PDUs BCH, FCH, ACH and RCH are coded with PHY mode BPSK ½ as recommended by the H/2 DLC specification [3].

Each subnet is coordinated by a CC that communicates to all WTs of its subnet via signaling connections, so called DCCH. With the *MF*-WT associated to CC1 and CC2, it holds signaling connections to both whereby a DCCH becomes active when the *MF*-WT is present at the corresponding subnet. For reasons of simplification the DCCH connections are not included in Fig. 5.

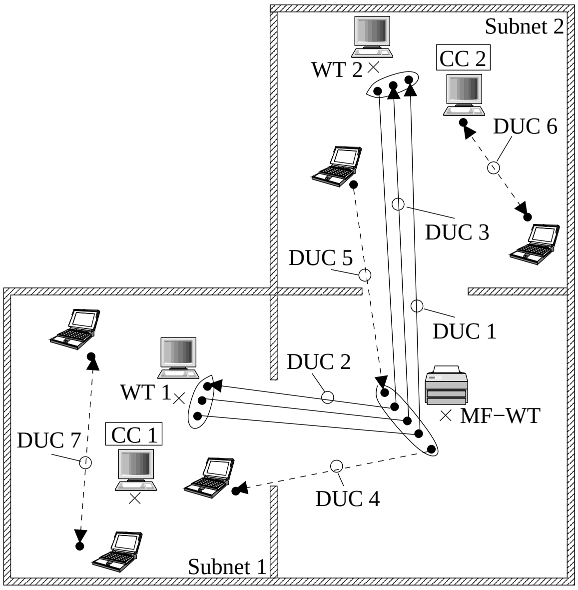

Fig.5: Two H/2 Ad Hoc Subnets Interconnected by one *MF*-WT

The diagram shows all DLC user connections (DUCs) that have been considered dependent on the simulation focus. Three *inter*-subnet connections DUC 1-3 provide examinations of unidirectional and bidirectional traffic as well as traffic with different QoS requirements that is exchanged in parallel between the subnets. To evaluate the effects caused by a mix of *inter*-subnet and *intra*-subnet traffic to and from the *MF*-WT, the DUCs 4 & 5 are loaded. With the DUCs 6 & 7 it can be investigated whether *intra*-subnet traffic that does not involve the *MF*-WT causes any influence on the forwarding mechanism.

Regarding QoS the following classification was defined for IP traffic [7]: *Best Effort Services*, *Differentiated Services* and *Integrated Services*. Traffic generators for these types of load are available. Simulations have been performed for *Best Effort Services* modelled by a scalable Poisson traffic source and *Differentiated Services*. Latter are represented by three MPEG video streams of 2.21 Mbit/s, 2.37 Mbit/s and 3.76 Mbit/s that are not correlated to each other. The MPEG video traffic source has been derived from a trace file provided by [13] with an fixed interarrival time of 41.7 ms respectively 24 video frames per second.

4.2 Analysis of Maximum Throughput and Mean Delay

In order to find out the performance capability of an *MF*-WT based on the RLC procedures *MT-Absence* and *MT-Alive*, the *inter*-subnet throughput was analysed for unidirectional and bidirectional Poisson traffic. The absence periods of the *MF*-WT have been chosen symmetrically for both subnets. In Fig. 6 the throughput characteristics for different load conditions are plot against the absence period length (mt-alive-time) that is given in the unit of H/2 MAC Frames (2ms).

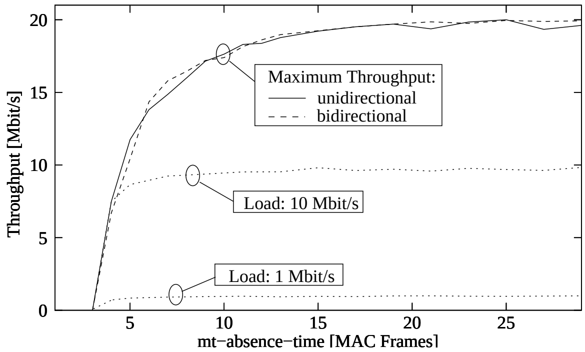

Fig. 6: Throughput vs. Absence Time

The maximum throughput values have been derived from simulation series whereby throughput and delay were evaluated dependent on load and absence time. The curves depicted in **Fig. 6** point to the following results:

1. There is a lower limit for the absence time of four MAC Frames. For three MAC Frames and below no forwarding is possible at all. This effect can be explained with the MAC Frames lost by frequency switching to the subnet and back, by synchronization to the new BCH, and by resource request and signaling effort.
2. The maximum throughput of unidirectional and bidirectional connections does not diverge significantly whereby for the bidirectional connection the througput of both directions have been summed up. The throughput limitation of *inter*-subnet connections is close to 20 Mbit/s (64 QAM ¾) that is approximately 44 % of the maximum possible *intra*-subnet traffic that has been found out in [7] to be 45 Mbit/s.
3. For a very low traffic load of 1 Mbit/s the throughput is nearly constant independently from the absence time. In case of a medium load of 10 Mbit/s a reduction of throughput is conceivable for an absence time below 8 MAC Frames.

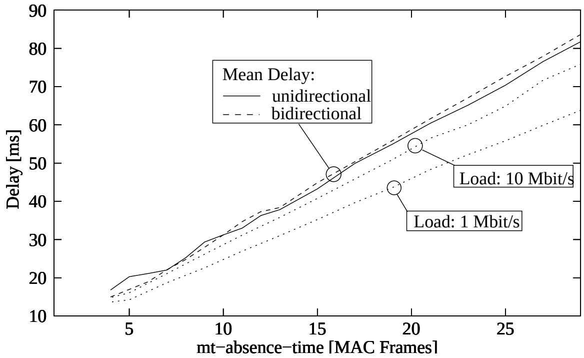

Fig. 7: Packet Delay vs. Absence Time

Beside the maximum throughput, the packet delay is the second characteristic parameter describing the performance of an *MF*-WT. In **Fig. 7** the packet delay versus absence time plot is shown. The mean delay curves represent the average of delays over the complete load spectrum up to the maximum load except the saturation phase. Based on the diagram following conclusions can be drawn:

1. The relation of delay to absence time is linear. Only slight divergences of unidirectional and bidirectional traffic are conceivable.
2. The delay increases with the traffic load whereby the curve for an 1 Mbit/s load approximates the lower limit.
3. A minimum end-to-end packet delay of 14 ms is achievable.

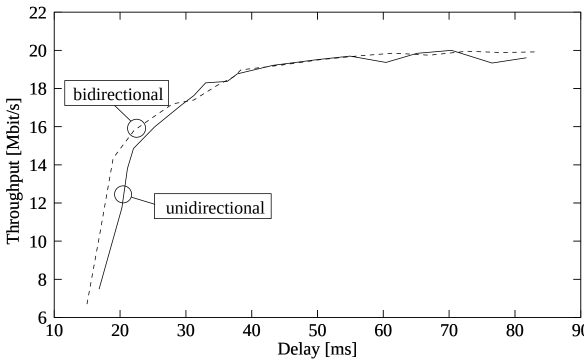

Fig. 8: Maximum Throughput vs. Mean Delay

By combining the results for maximum throughput and mean delay to one plot, **Fig. 8**, the set of possible operation points of an MF-WT can be identified as the area below the curves. By this representation a slight better characteristics regarding the delay can be detected for bidirectional connections compared to unidirectional connections. This effect will be investigated in further studies – one reason could be that for bidirectional connections two buffer queues, one per direction, are allocated resulting in lower queue lengths at the *MF*-WT.

4.3 Effects Caused by a Phase Shift of the Subnets´ Frame Synchronization

For the proposed *multiple-frequency* forwarding technique there is no requirement to synchronize the MAC Frames of both subnets to be interconnected. In order to get an impression of the effects that may result from a phase shift of the frame synchronization, the CC of the second subnet has been delayed to the CC of the first subnet (CC 1). The absence time was set to 11 MAC Frames for this scenario.

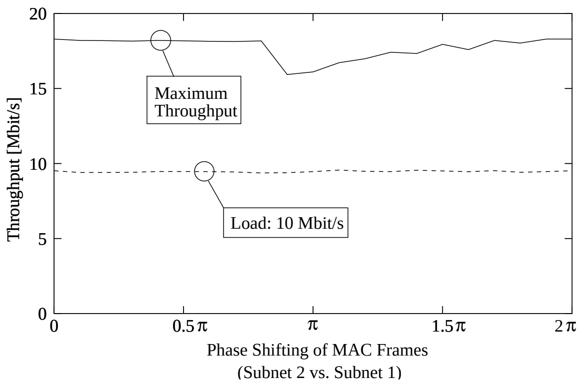

Fig. 9: Phase Shift Influences on the Throughput

As it can be seen from **Fig. 9,** only the maximum throughput of the *inter*-subnet-connection from subnet 1 to subnet 2 is influenced by the phase shift whereas no deviation can be noticed when a load of 10 Mbit/s is chosen. The reduction of the maximum throughput in the range from 0.9π (16%) to 1.4π (6.5%) indicates hostile conditions resulting in the partial or steady (0.9π) unavailability of one MAC Frame for the presence phase of the *MF*-WT at a subnet.

4.4 *MF*-WT serving both *Inter*-Subnet and *Intra*-Subnet Traffic

Owing to the fact that the *MF*-WT serves all *inter*-subnet-DUCs as well as concurrent *intra*-subnet-DUCs destined for itself it has to be seen as scarce resource. To create a corresponding simulation scenario, DUC 4, see Fig. 5, has been assigned a 2.21 Mbit/s MPEG video stream sent by the *MF*-WT when it is present in subnet 1. In a second scenario an additional 2.37 Mbit/s MPEG video stream is received by the *MF*-WT via DUC 5 when it is present at subnet 2. With an absence time of 8 MAC Frames and a higher priority for the MPEG traffic than for Poisson traffic all QoS requirements can be guaranteed.

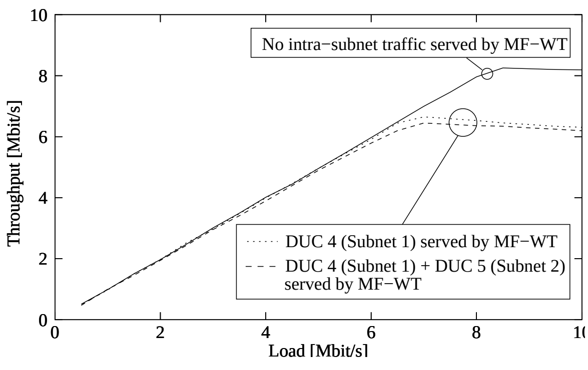

Fig. 10: *Inter*-Subnet Traffic, Throughput vs. Load

As described in Fig. 5, for bidirectional *inter*-subnet traffic the DUC 1 & 2 are used whereby DUC 2 is directed from subnet 2 to subnet 1. In **Fig. 10** the throughput of DUC 2 is plot against the traffic offer.

The respective results for the packet delay are depicted in **Fig. 11**.

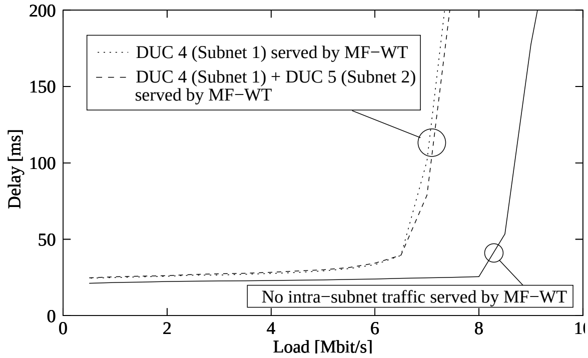

Fig. 11: *Inter*-Subnet Traffic, Delay vs. Load

From both diagrams the saturation level of DUC 2 can be detected for the three simulation scenarios:

1. Only *inter*-subnet traffic is served by the *MF*-WT
2. The *MF*-WT additionally serves DUC 4
3. It additionally serves DUC 4 & 5

The comparison of scenario 1 & 2 shows that, if the *MF*-WT serves *intra*-subnet traffic in the destination subnet, the maximum throughput of the *inter*-subnet DUC is reduced approximately for the additional load. For the case of DUCs served in the source subnet, however, the inter-subnet DUC is scarcely influenced.
This interesting effect is caused by the resource request mechanism. Before the *MF*-WT is able to deliver its buffered *inter*-subnet PDUs, it first has to request resources resulting in one unusable MAC Frame. In contrast, resources for data transfer to the *MF*-WT have already been requested in the absence phase of the *MF*-WT. Thus the CC is able to grant these resources immediately for that MAC Frame the *MF*-WT is calculated to be present again. For DUC 1 the same characteristics can be observed. However, the saturation level is slightly higher because of the fact that the PDUs of DUC 5 are received by the MF-WT and not sent as those of DUC 4 inducing lower overhead.

4.5 QoS Support for *Inter*-Subnet Links

An essential advantage of HiperLAN/2 in comparison to competing wireless LANs is the support of QoS. This ability - to differentiate mission-critical and non-mission-critical services [7] - should also be provided by H/2 multihop ad hoc network configurations. In order to evaluate whether the *MF*-WT technique is capable of H/2 QoS requirements, an higher prioritized MPEG video stream was transmitted together with an scalable bidirectional Poisson load via the *inter*-subnet link.

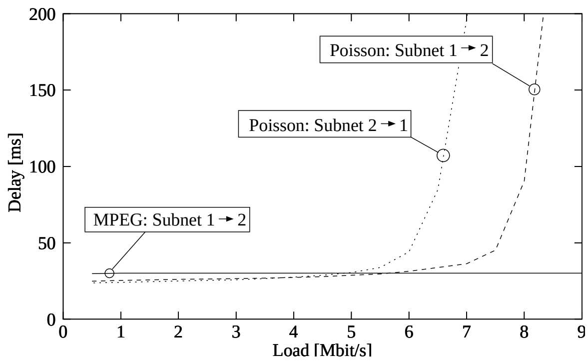

Fig. 12: Delay of forwarded DUCs

From the results, presented in **Fig. 12**, it can be concluded that QoS support is possible. As conceivable from the delay vs. load plot, the mean delay of the MPEG traffic does not vary even for the case that the lower priority connections reach their saturation level.
With the Poisson load set to 6 Mbit/s per direction, the Complementary Distribution Function (CDF) of packet delays was analysed, see **Fig. 13**. The 3.76 Mbit/s MPEG video stream is preferred compared to the best effort traffic. However, the selected absence time of 8 MAC Frames is the upper limit for this load situation because 2.3 % of the PDUs carrying MPEG traffic exceed the critical delay of 41 ms. This problem could be solved by an decrement of the absence time reducing the best effort traffic at the same time or by speeding-up the MPEG traffic source allowing transmission of more than 24 video frames per second.

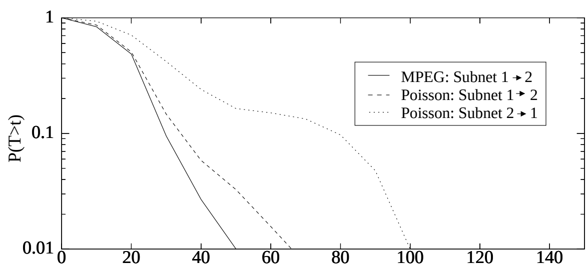

Fig. 13: CDF of the Packet Delay

In order to serve even *Integrated Services*, some additional effort is necessary to minimize the forwarding overhead.

4.6 Influence of *Intra*-Subnet Traffic on Forwarded Traffic

The two-subnet configuration has been examined under high load conditions, meaning that two 2.5 Mbit/s Poisson plus one 3.76 Mbit/s MPEG *inter*-subnet DUCs are served by the *MF*-WT as well as a 2.21 Mbit/s MPEG DUC in subnet 1 and a 2.37 Mbit/s MPEG DUC in subnet 2. Additionally, the DUCs 6 & 7 carry Poisson traffic that is incremented up to 20 Mbit/s each. No saturation effects could be recognized showing that the intra-subnet traffic – except that traffic the *MF*-WT is involved – does not influence the *inter*-subnet communication significantly and vice versa.

5 Conclusions and Outlook

The novel concept for interconnecting H/2 ad hoc subnets presented in this paper can be utilised in ETSI-BRAN HiperLAN/2 Home Environment devices without major changes. It extends the “one hop” ad hoc network topology currently available to a multihop connectivity. The forwarder concept proposed is based on an alternating intermitted presence of *MF*-WTs at the involved frequency channels and supports user connections among any WTs located in the interconnected subnets. An *MF*-WT that is present in one subnet emulates the other subnet and caches the PDUs to be transferred. Performance analyses regarding maximum throughput, delay characteristics, QoS support etc. show that this technique is well applicable for H/2 ad hoc networks. In future studies the “alternating forwarder” principle proposed in this paper additionally will be investigated expecting further optimizations of *inter*-subnet connectivity.

6 Literature

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