A Centralized Ad-Hoc Network Architecture (CANA) Based on Enhanced HiperLAN/2

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Abstract— **In ad-hoc networks, where a user can enter, leave or move inside the network with no need for prior configuration, the support of multimedia applications that require very high bit-rates, is a challenging problem. Here, a *Centralized Ad-Hoc Network Architecture* (CANA) is proposed, capable of efficiently supporting those applications in low mobility environments, while at the same time a standard wireless LAN environment is maintained for fast moving users. CANA is based on an enhanced HiperLAN/2 protocol architecture [1] [2], (even though this is not mandatory) that supports a dual mode of operation at 5 GHz and 60 GHz. In this system architecture, several ad-hoc specific functionalities are included, such as *neighborhood discovery*, *clustering* and *routing*. Among them, switching between different modes of operation has a large impact on the achievable performance of CANA.**

I. Introduction

Modern networked multimedia applications require certain *Quality of Service*, such as high bit-rates and small delays, to be effectively supported. Moreover, users demand access to these applications any time, anywhere. While existing wireless LAN standards such as IEEE 802.11 legacy [3], and *High Performance Radio Local Area Network type 2* (HiperLAN/2) [1] [2], provide a fair coverage range to the mobile users , the supported bit-rate can be inadequate for very high bit-rate applications, especially in high user density areas.

Ad-hoc networks represent a smart solution to support users' demand but their intrinsic characteristics make the QoS requirements hard to be satisfied. Here, an innovative *Centralized Ad-Hoc Network Architecture* (CANA) is proposed, capable of supporting applications that require high bit-rates in an ad-hoc environment. The considered ad-hoc environment corresponds to a second mode of operation of a wireless LAN, in addition to the standard mode.

The framework of this paper is the IST Broadway project [4]. The considered wireless LAN is HiperLAN/2 [1] [2], operating at 5 GHz. The second mode of operation introduces the use of the 60 GHz band, with ad-hoc capabilities, for the support of very high bit-rate applications. The approach is to improve system performance in high traffic scenarios combining the standard mode of operation at 5 GHz with ad-hoc features at 60 GHz. Under certain conditions, the 5 GHz band is offloaded by employing the introduced ad-hoc operation at 60 GHz. The *Access Point* (AP) coordinates the ad-hoc operation of the *Mobile Terminals* (MTs).

Two different equipment types are considered. The first, used by the AP, operates at both frequency bands simultaneously, whereas the second, used by the MT, operates either at 5GHz or at 60 GHz (requiring a switching between the two bands).

The main reason for using a second mode of operation at 60 GHz is that at least 3 GHz of spectrum are available from 59 GHz to 62 GHz. In CANA, channels with 80 MHz of bandwidth are used supporting rates up to 160 Mbit/s at the physical layer. The overhead associated with this strategy is introduced by mechanisms such as the neighborhood discovery and the centralized routing algorithm [5] along with the signaling for the offloading itself.

CANA is described in Section II, while in Section III the enhanced HiperLAN/2 protocol stack is presented. In Section IV, different possible strategies for the realization of CANA are analyzed and evaluated. It is shown that the adopted approach is effective as far as offloading the 5 GHz band is concerned. Finally, the conclusions are drawn in Section V.

II. Centralized Ad-Hoc Network Architecture

The AP operates simultaneously at both frequency bands (5 GHz and 60 GHz). The AP determines its own 60 GHz frequency channel, and decides for the particular 60 GHz frequency channels to be used by the MTs. CANA is based on the fundamental principle that the AP is responsible for all operations of the MTs that belong to its 5 GHz coverage range, and is responsible for the efficient offloading of the 5 GHz band by commanding certain sets of MTs to switch to the 60 GHz mode and use a dictated 60 GHz frequency channel [4].

A. Overview

The dual mode of operation defines two operational regions: one at 5 GHz and one at 60 GHz. The AP always plays the role of the standard access point for the MTs that are tuned at 5 GHz inside the HiperLAN/2 cell. Its 60 GHz channel defines the radius of a smaller cell; every MT that belongs to this cell and is tuned at the specific 60 GHz frequency channel of the AP is part of the so-called AP's *cluster*. A cluster is defined as the set of equipments synchronized to a particular frame at a specific 60 GHz frequency channel. The AP undertakes the role of the *Cluster Head* (CH) - described below - inside its cluster. The role of the AP at 60 GHz is similar to the standard at 5 GHz.

Clusters are dynamically formed by the AP based on the traffic requirements inside the HiperLAN/2 cell and the topological information concerning the 60 GHz band (connectivity status of neighboring MTs). Any MT may assume the role of a CH for a particular cluster and for a specified time period. CHs are mainly responsible for generating the frame at the chosen 60 GHz frequency channel and forwarding traffic inside their clusters. Clusters are not only distinguished based on their participants but also on their frequency channel. Although 60 GHz frequency channels can be reused inside the HiperLAN/2 cell, no adjacent clusters are assigned the same channel.

Data sessions can include MTs that belong to adjacent clusters; then, one MT plays the role of a *Forwarder Node* (FN). A FN needs to switch between different 60 GHz frequency channels and acts as a gateway between adjacent clusters. The AP is responsible for assigning a FN for a specific data session and informing the corresponding CHs. Ordinary nodes are neither those that are CHs nor FNs.

The overall network is depicted in Figure 1. It can be observed that clusters may or may not be isolated. MTs that do not belong to any cluster continue to operate in the standard 5 GHz mode of operation.

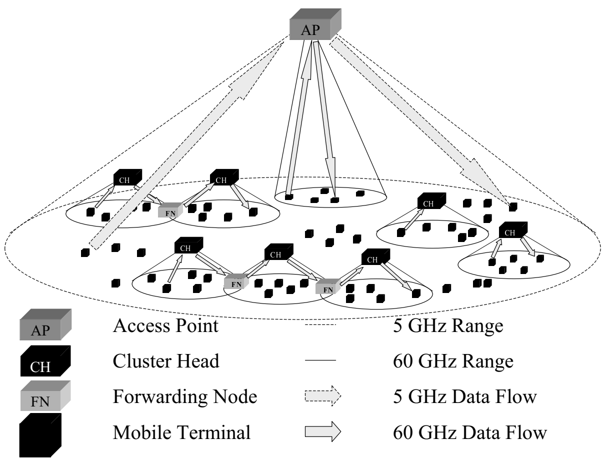

Figure 1. Network Architecture.

B. Routing in CANA

The main purpose of CANA is to offload the 5 GHz band. This can be achieved by supporting the dual mode of operation and providing for a robust routing algorithm to manage communication at 60 GHz. CANA is realized via the formation of clusters - *clustering* - that also supports routing data at 60 GHz. Clustering is performed on-demand under increased traffic conditions. The information required in order for the AP to make clustering decisions includes the connectivity status of MTs at 60 GHz.

The procedure, which provides the necessary information to the AP is referred to as *neighborhood discovery* [5]. To initiate neighborhood discovery, the AP asks all MTs inside the HiperLAN/2 cell to participate in a hello message exchange at 60 GHz. This way, every MT constructs a neighborhood table consisting of the one-hop away MTs and the corresponding link status and then transmits its table to the AP using the 5 GHz band. Neighborhood discovery is performed periodically or on an event-driven basis.

Routing in CANA is the AP's responsibility. The AP determines the time instances that a MT should switch to a predetermined 60 GHz channel, the number of frames to spend at the new frequency, the assignment of MTs' roles, the initiation of neighborhood discovery and the allocation of the available frequency channels among the clusters operating at 60 GHz.

Since the main focus of this work is on the architecture, the description of routing algorithms is out of the scope of this paper.

C. Data Sessions

Data sessions between MTs that belong to the 5 GHz range of the AP, can always use the 5 GHz mode of operation. For the network architecture depicted in Figure 1, three different types of data sessions at 60 GHz can be defined, according to their source and destination.

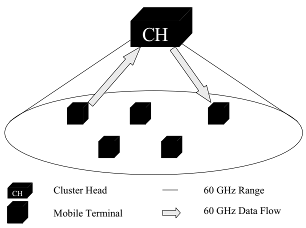

Figure 2. Intracluster Data Session.

The first corresponds to the case where both end points of the data session belong to the same cluster, as it is depicted in Figure 2. This case is called *intracluster* data session; the CH forwards all data packets from their source to their destination. The second type of data session corresponds to the case where data need to be exchanged between clusters, for which a path can be established along a sequence of FNs of adjacent clusters. This case is called *intercluster* data session and is depicted in Figure 3. Various active data session types that can be supported simultaneously under CANA are depicted in Figure 1. It can be seen that if there is no path through FNs for a certain destination, then the standard 5 GHz mode of operation is used.

Intracluster data sessions are preferable compared to the intercluster ones. This is obvious, since the number of hops for intercluster data sessions is larger and involves FNs which have to switch between the specific frequencies of the adjacent clusters. Therefore, the selection of the clusters is a critical issue. Certainly, the highly desirable scenario corresponds to the case

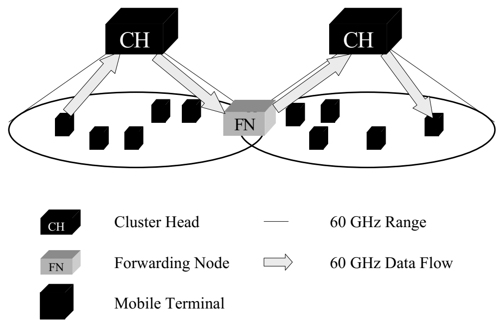

Figure 3. Intercluster Data Session.

where a CH is one of the end points of the data session for an intracluster data session.

One case of special interest corresponds to the operation of the system when no AP is present; then, all MTs not being able to associate to an AP, switch to a predetermined frequency channel at 60 GHz and elect a CH in a distributed manner. This case graphically corresponds to Figure 2, and additional functionalities are required for its realization.

III. Enhanced HiperLAN/2 Protocol Architecture

The network architecture presented so far is capable of offloading the 5 GHz frequency band, since large amounts of data can be forwarded through 60 GHz links whenever possible. In order to support this operation, the standard HiperLAN/2 protocol stack has been enhanced and certain features have been added in the *Physical Layer* (PHY), the *Data Link Control Layer* (DLC), as well as the *Convergence Layer* (CL).

CL is divided into two sublayers: the *Service Specific Convergence Sublayer* (SSCS) [6], which is the highest part of the protocol stack and targets at efficiently adapting to the higher layers (Ethernet or IP), and the *Common Part Convergence Sublayer* (CPCS) [7], where mainly segmentation and reassembly of the data packets take place. The standard HiperLAN/2 protocol stack can be seen in Figure 4. The *User Plane* corresponds to the functionalities that are specific for the user data, whereas the *Control Plane* corresponds to the control functionalities.

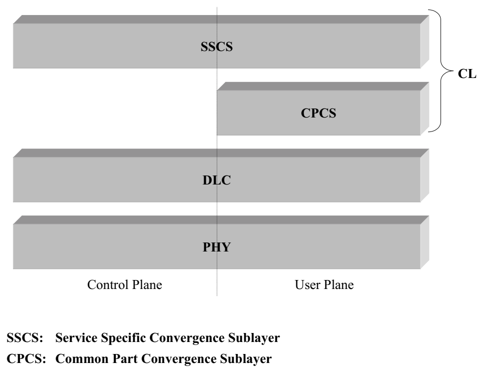

Figure 4. Standard HiperLAN/2 Protocol Stack.

The description of the required enhancements at PHY in order to support the 60 GHz mode of operation are out of the scope of this paper. Here, the focus is on how CL supports CANA, and the specific DLC modifications that enable the proposed enhancements. In the CL, only the SSCS needs to be enhanced. For the rest, CANA-SSCS and CANA-DLC denote the enhanced SSCS and DLC for CANA, respectively. Figure 5 depicts the enhanced architecture that enables the support of the operations required for the realization of CANA. The dark grey boxes refer to the enhanced layers of the protocol stack. Their functionalities are presented in the sequel.

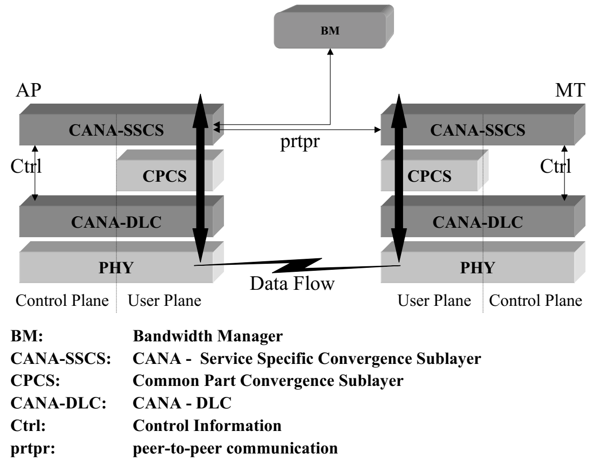

Figure 5. Enhanced HiperLAN/2 Protocol Stack for CANA support.

The enhanced protocol stack is capable of providing direct communication (*prtpr*) between the AP and a MT (at the SSCS layer), in order to support certain operations required by the ad-hoc nature of the network at 60 GHz. In Figure 5, the direct communication (prtpr) between CANA-SSCS for the AP-to-MT case is depicted. Operations such as neighborhood discovery, clustering and routing are important for the realization of the network architecture and require communication not only between the AP and each MT at 60 GHz, but also directly between the MTs (prtpr for the MT-to-MT case is similar to the AP-to-MT case).

The AP may also receive requests from external entities, that describe certain QoS requirements. This is denoted with the communication arrow between CANA-SSCS and another external entity called *Bandwidth Manager* (BM), as it is depicted in Figure 5. The underlying QoS model is possible to be the *Differentiated Services* model, [8].

CANA-SSCS is also responsible for maintaining tables for information that is required for the fine operation and coordination of the system operating in both modes. Each MT inside a cluster keeps information about the corresponding CH and the specific 60 GHz frequency channel in which the cluster operates. The CH keeps all information that is critical for the proper operation of the cluster. This corresponds to cluster specific information, such as the particular set of MTs that belong to the cluster and their characteristics (identification numbers, IP addresses, requests for resources, etc.). In addition, routing information is maintained. In particular, for each destination the CH is able to extract the appropriate FN that the data should be forwarded to. For each FN, the CH is aware of the set of frames that the FN will be present in the specific cluster.

DLC enhancements (or CANA-DLC) support the functionalities of CANA-CL by enabling the assignment of a dedicated connection for the prtpr communication depicted in Figure 5.

A dedicated connection will have the advantage that it will not require drastic changes to the HiperLAN/2 standard implementation, reducing design/implementation costs. This particular dedicated connection should be shielded with an error-control mechanism and it should be scheduled as high priority, since the carried control information is critical to be on time.

IV. CANA Evaluation

One of the crucial issues of CANA, that is investigated in this section, concerns the strategy that has been adapted in managing connections that must be offloaded through the 60 GHz band. In fact, a CANA-based system must take into account problems of signaling that concern the presence of clusters and CHs, the limited range of transmissions at 60 GHz along with the mobility of MTs, the periodical interruption in order to perform the neighborhood discovery procedure [5] and the fact that MTs cannot stay tuned at both 5 and 60 GHz in order to use at the same time the former band as a signaling channel and the second to perform data transfer. All these issues have to be traded off against the need for MTs to stay tuned as long as possible at 60 GHz to fully exploit the higher transmission speed.

A. Switching Strategies

In order to lighten the system functionality, all proposed switching mechanisms are based on the HiperLAN/2 framing structure. The aim is to ensure as much as possible the compatibility with the protocol stack of the latter system and to take advantage of its presence, proposing at the same time a strategy capable of exploiting the high bit-rates provided by the 60 GHz band. CANA could be based on numerous strategies; three of them - the basic ones - are examined in the sequel. The scenario used to describe and evaluate the various offloading strategies is a 5 GHz cell with MTs having a downlink connection with the AP at 5 GHz, and a direct-link connection with another MT which is in their 60 GHz range. The direct link connections can thus migrate at 60 GHz to offload the 5 GHz band.

The first strategy, depicted in Figure 6.a, assumes that the switching between different modes of operation takes place just after the *Broadcast* (Br) phase of the frame at 5 GHz. The particular switching follows a *Resource Request* (RR) applied during the previous frame. The second strategy, depicted in Figure 6.b, assumes that the switching to 60 GHz takes place after the 5 GHz *downlink* (DL) phase; that way, the MT is capable of communicating with the AP every frame. Note that during the second strategy the RRs are sent after the switching back to 5 GHz on a per frame basis, whereas in the first strategy a RR is sent every second frame.

The strategy adopted for CANA, depicted in Figure 6.c, is based on granting a flexible number of frames (n_{off_frames}) to the MTs that participate in a 60 GHz connection. The RR is performed in frame i, the allocation of the number of frames granted is communicated to the MTs in frame $i+1$, and the connections at 60 GHz are established in frame $i+2$.

B. Analysis of the Different Strategies

To evaluate the three strategies, the average throughput achievable per 60 GHz connection was computed, with the following assumptions: (a) error free transmission for data and

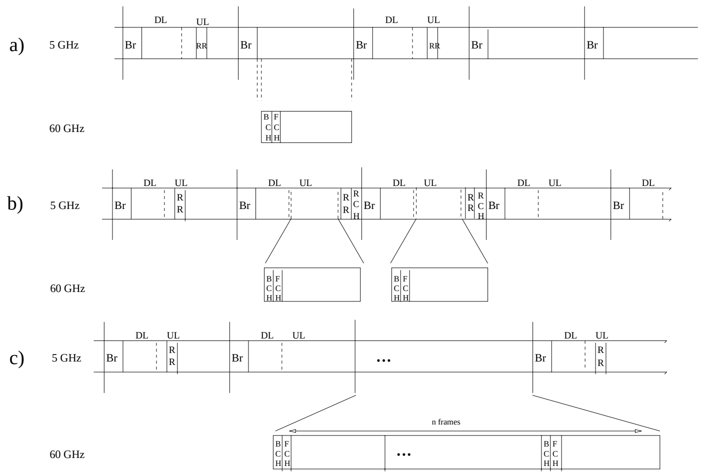

Figure 6. Switching strategies

control information; (b) there are 2 MTs and one connection per 60 GHz cluster and it is assumed that the sender is elected as CH; (c) there is no FN (only single-hop peer to peer traffic); (d) there is also 5 GHz downlink traffic of duration t_{DL} in every cluster, which represents a fixed percentage of the MAC frame duration t_{frame} (here, we assumed $t_{\mathrm{DL}} = 0.2 \times t_{\mathrm{frame}}$); (e) the layout of the 5 GHz frame is the same used for HiperLAN/2; (f) every 60 GHz link can occupy a different 60 GHz channel, assuming there is no co-channel or inter-channel interference. This assumption is justified by the large number of channels available at 60 GHz (up to 37 channels of 80 MHz are available in the 59-62 GHz band), and by the high attenuation by obstacles at those frequencies; (g) the switching time between the 5 and the 60 GHz band is fixed to 50 μs, due to RF constraints studied in the Broadway project; (h) the time needed to process a FCH is 120 μs and the additional signaling required for the 5/60 dual mode of operation is neglected. FCH, BCH, ACH, RCH, SCH are HiperLAN/2 standard channels [2].

For 60 GHz links, 80 MHz channels are considered. The OFDM parameters are an FFT size of 256, with 184 useful sub-carriers, a total symbol duration of 3.6μs with 400 ns guard interval. The modulation is 16QAM with code rate $\frac{3}{4}$for data traffic and BPSK with code rate 1/2 for signaling, leading to bit-rates of respectively $BD_{60} = 160Mbps$ and $BS_{60} = 26.7Mbps$. For the 5 GHz signaling (BCH, FCH etc.), the 6 Mbit/s mode is selected. Finally, the format of the 60 GHz frame (BCH_{60}, FCH_{60}) does not foresee the use of the RCH and ACH channels since association is already performed at 5 GHz.

With respect to the strategies illustrated in Figure 6, the following analytical expressions for the evaluation of the throughput at the MAC layer have been derived.

The first strategy (Figure 6.a) yields the following throughput

$$T_a = \frac{t_{\mathrm{avail}} \times BD_{60}}{2 \times t_{\mathrm{frame}}}, \tag{1}$$

where

$$\begin{aligned} t_{\mathrm{avail}} &= t_{\mathrm{frame}} - t_{\mathrm{BCH}} - t_{\mathrm{FCH}} - t_{\mathrm{ACH}} - (t_{\mathrm{proc}} - t_{\mathrm{ACH}}) \\ &\quad -2 \times t_{\mathrm{switch}} - t_{\mathrm{BCH}_{60}} - t_{\mathrm{FCH}_{60}}. \end{aligned}$$

For the second strategy (Figure 6.b)

$$T_b = \frac{t_{\mathrm{avail}} \times BD_{60}}{t_{\mathrm{frame}}}, \tag{2}$$

but in this case

$$t_{\rm avail} = t_{\rm frame} - t_{\rm BCH} - t_{\rm FCH} - t_{\rm ACH} - (con\_id \times t_{\rm SCH}) - t_{\rm DL} - t_{\rm RCH} - 2 \times t_{\rm switch} - t_{\rm BCH_{60}} - t_{\rm FCH_{60}},$$

where con_id is the number of active connections (note that the number of connections influences the second strategy only, due to the applied RRs in every frame). Finally, for the chosen strategy (Figure 6.c) the throughput is given by

$$T_c = \frac{n_{off\_frames} \times (t_{\rm frame} - t_{\rm BCH_{60}} - t_{\rm FCH_{60}}) \times BD_{60}}{n_{off\_frames} \times t_{\rm frame}}. \quad (3)$$

In figure 7, the average offloaded throughput per connection versus the number of connections for the three strategies is illustrated.

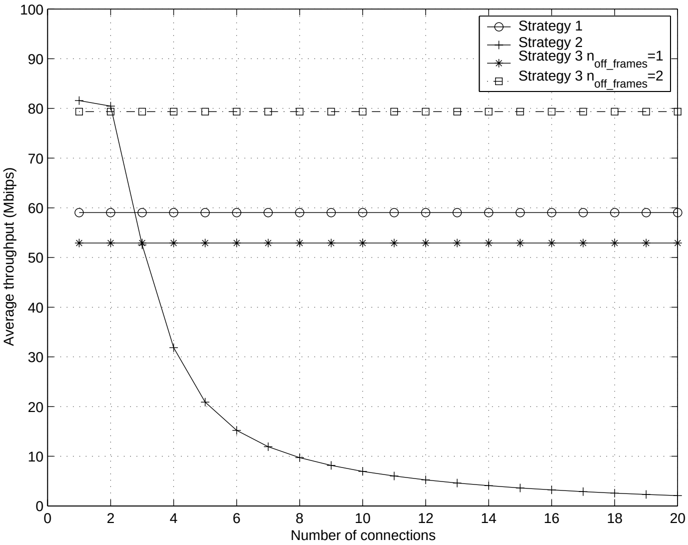

Figure 7. Average throughput per connection, considering con_id =1 to 20 connections and $t_{DL} = 0.2 \times t_{\rm frame}$

It can be observed that there is a significant difference between the throughput achieved by the three strategies. In fact, even under low traffic load, the third strategy (Figure 6.c) allows for the highest throughput, while the other two exhibit similar performance only in case of few connections, because the part of the 5 GHz MAC frame that is used for signaling messages like RRs and FCH increases as the number of connections increases, afflicting mostly the second strategy. Note that the third strategy outperforms the other two for $n_{off\_frames} \geq 2$ since the average throughput per 60 GHz connection is 80 Mbit/s, which represents 50% of the raw bit-rate. In other words, the maximum cell throughput can amount to 800 Mbit/s when 10 connections can migrate to 60 GHz. This illustrates the use of the 60 GHz band in heavy traffic scenarios. Further improvement of throughput can be achieved by increasing the value of n_{off_frames}.

The drawback of the third strategy is that MTs cannot hear any message from the AP for n_{off_frames} consecutive frames, because they are not able to monitor signaling information. The value of n_{off_frames} is decided by taking into consideration the particular topology characteristics (mobility, users' density) and the traffic requirements (load, end points of connections). Consequently, the AP assumes a crucial role for scheduling the strategy to efficiently offload the 5 GHz band in CANA.

V. Conclusions

This paper explores the idea of an innovative centralized adhoc network architecture, called CANA. The architecture's capability of offloading the HiperLAN/2 5 GHz standard mode of operation is explored and its effectiveness is investigated. The proposed architecture is shown to be capable of supporting applications with very high bit-rate requirements.

The main characteristic of CANA is that it allows for a dual mode of operation into the traditional HiperLAN/2; the frequency channels at 60 GHz offload data traffic in dense environments with low mobility whereas the 5 GHz frequency can always be a back-up frequency when users move faster. This network architecture can be realized by an enhanced HiperLAN/2 system. The enhanced HiperLAN/2 system requires certain changes of the standard HiperLAN/2 protocol stack to incorporate the ad-hoc functionalities at 60 GHz, as discussed in this work. The evaluation of different strategies shows that long-term resource assignments improve the system's performance and the adopted strategy for CANA is the most efficient. Special algorithms, such as neighborhood discovery, clustering and routing, have to be incorporated in the CL for the efficient use of the system resources.

In conclusion, CANA is capable of providing high bit-rates for modern multimedia applications in an ad-hoc environment, while maintaining the standard HiperLAN/2 mode of operation, as well as offloading the crowded 5 GHz band in dense areas.

VI. Acknowledgement

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