On Supporting Dual-Mode HiperLAN/2: Architecture and Overhead

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ABSTRACT

The IST BroadWay project, [1], introduces the ad-hoc networking paradigm in the traditional 5 GHz HiperLAN/2. The ad-hoc networking paradigm is employed at the 60 GHz frequency band, which allows for a high transmission rate communication. The dual mode of operation primarily aims at offloading the 5 GHz HiperLAN/2 cell in very dense urban deployments (high traffic needs and number of users), while the peculiarities of the BroadWay environment induce modifications on the existing HiperLAN/2 system and make the development of a routing scheme a rather challenging task. The *Centralized Ad-hoc Network Architecture* (CANA) is an efficient way to support dual mode systems, [2], by implementing specific changes and algorithms in the standard HiperLAN/2 protocol stack. In this paper, the new enhanced protocol stack of dual-mode HiperLAN/2 is presented as well as the algorithms required for the efficient utilization of the system resources. Simulations provide insight into the performance issues regarding the dual mode of operation and the parameters that affect the efficiency of the described network model.

I. INTRODUCTION

The limited bandwidth that is shared among the users, the error-prone environment, the lack of secure transmissions and the scarceness of energy resources are some of the challenges that need to be taken into consideration in wireless communications and may limit their performance. On the other hand, the recent advances in computing and wireless technologies promise to efficiently cope with the above limitations while, at the same time, the user requirements to have access to high bit rate modern applications any time, anywhere impose the need for hybrid wireless networks; such systems should support the accessibility by heterogeneous devices, as well as be possibly backward compatible.

CANA has been proposed to efficiently take advantage of the ad-hoc networking paradigm inside infrastructure-based WLANs, [2]. CANA is an architecture for hotspots including private (i.e. e-home entertainment, business) and public (i.e. fast outdoor downloading) applications. It is designed to cope with very dense user environments without sacrificing the user expectations in terms of *throughput*. The primary objective of CANA is to establish a bridge between the 5 GHz band and the unlicensed radio spectrum in the 59-65 GHz range by conceiving a dual frequency WLAN that will provide for a smooth evolution to the 60 GHz from the existing 5 GHz technology, with backward compatibility and increased total system capacity.

The basic WLAN architecture employed is HiperLAN/2 (HL/2), [3], to which ad-hoc functionality is added in the 60 GHz frequency band (short ranges). CANA may be viewed as a first step toward a new platform that would provide for an integrated WLAN/WPAN technology capable of meeting user expectations in terms of throughput and sophisticated applications.

The propagation effects at 60GHz and previous research results and experiments, [4], suggest that the 59-65 GHz band is well suited for CANA: i) a large chunk of spectrum is available enabling a very large system capacity (high rates in short distances up to 160 Mbps at the physical layer, [1]) and ii) the short-range operation facilitates privacy and allows for aggressive frequency reuse.

CANA imposes the incorporation of certain algorithms in order to support the new network model. The *Neighborhood Discovery* (ND) algorithm, [5], that identifies the neighborhood of a MT, and the *Broadway Routing* (BWR) that deals with cluster creation and routing information, are required for the fine operation of CANA. To efficiently use the aforementioned algorithms, several functional modules are proposed enhancing the standard protocol stack of HL/2.

In the following section, the induced dual mode of operation is described. In section III, CANA modules to support dual-mode HL/2 are depicted while, in section IV, simulation results address some of the performance issues of CANA. In section V, the paper is concluded.

II. DUAL MODE OF OPERATION

One main peculiarity in CANA is the existence of two separate frequency bands. This situation differs from frequency division multiplexing – where frequencies belonging to the same band are utilized – since the two bands are characterized by entirely different propagation characteristics and resource (bandwidth) availability, as well as require different hardware implementations to support them. This “gap” between the two bands becomes evident during the operation of the system due to the fact that each *Mobile Terminal* (MT) operates at only one band at each time instant; because of cost constraints, each MT is equipped with only one *Radio Frequency Front End* (RFFE). Consequently, two network topologies are defined: the 5 GHz and the 60 GHz.

The *Access Point* (AP) is equipped with two RFFEs and is always active in both network topologies with a different coverage area for each band, resulting in – virtually – two APs: the 5 GHz AP and the 60 GHz AP. Due to the different propagation effects in the two bands (as mentioned earlier) the coverage area of the 60 GHz AP is significantly smaller than that of the 5 GHz AP. Consequently, in order for MTs to reach the 60 GHz AP when outside its small coverage area, a multi-hop path needs to be established. CANA allows for the efficient establishment of multi-hop routes inside a cell.

The 5 GHz AP generates TDMA frames with duration of 2ms and forwards data on behalf of the MTs to the corresponding destination as standardized in HL/2, [5]. Moreover, it is responsible for allocating the resources associated with *both* frequency bands. Every MT that is inside the 5 GHz AP's cell is associated with it. MTs tune at 5 GHz at first (association with the 5 GHz AP) and operate at 5 GHz most of the time, unless they participate in an established 60 GHz path, as explained later. Association with and connections at 5 GHz are established as described in the HL/2 standard, [3].

A similar TDMA structure as in HL/2 is applied to assure compatibility; the frames at 60 GHz have the same length as those in HL/2 (2ms). The transmission rates vary depending on the applied modulation scheme, the constellation size and the cost of the MT, [1]. Several frequency channels may be used within the 60 GHz band.

The 60 GHz AP operates at a predefined 60 GHz channel, generating frames as in the 5 GHz band; it does not switch between 60 GHz frequency channels. The 60 GHz AP is responsible for the MTs that belong to its coverage area and are tuned to its 60 GHz channel. It stops generating frames at 60 GHz only during the *Neighborhood Discovery* (ND) process. MTs can operate in any of the available 60 GHz channels, which can be different at different times. They may be tuned to any of the available 60 GHz channels if asked by the 5 GHz AP, to participate in an established 60 GHz path or the ND process.

CANA defines three different roles for the MTs that operate at 60 GHz that are all assigned by the 5 GHz AP: a) Cluster Head (CH), b) Forwarder Node (FN), and c) Common Node (CN).

A CH is a MT that generates frames at 60 GHz and controls the communication resources for the MTs in its coverage area (*cluster*), that is, hear its transmissions. The role of a CH in CANA is primarily routing data, since the resource allocation is mainly the 5 GHz AP's responsibility. The CH assumes a resource allocation responsibility only to control one-hop and two-hop communication inside its cluster (*intra-cluster* communication), taking in this case some of the traffic management burden from the 5 GHz AP. The 60 GHz AP can be considered as a CH that never switches back to 5 GHz.

Adjacent clusters operate at different 60 GHz frequency channels to avoid interference. A FN is a MT that can hear the transmissions of more than one CHs and switches between different 60 GHz frequency channels to enable *inter-cluster* communication (more than two-hop communication).

All other MTs are CNs. A CN is considered to be part of a cluster if it hears the frame of the associated CH.

Figure 1 depicts a time instant of CANA showing the three different roles of a MT at 60 GHz.

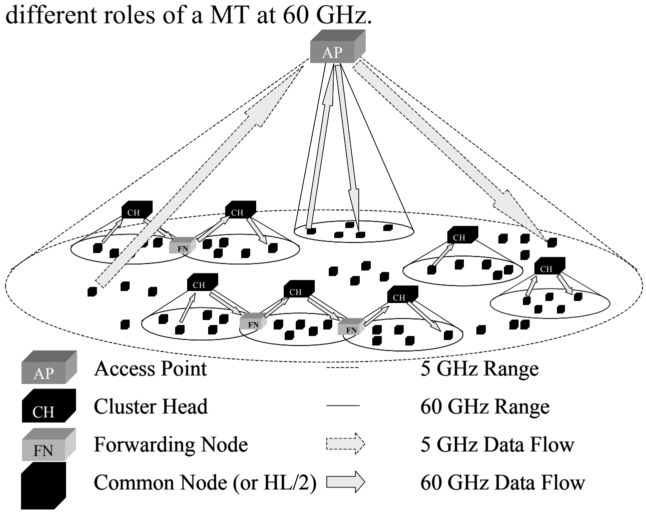

Figure 1: A time instant of CANA

III. ALGORITHMS AND MODULES OF CANA

Routing in CANA is designed to effectively combine the ad-hoc networking paradigm at 60 GHz and the cellular networking paradigm at 5 GHz.

Routing at 5 GHz is rather straightforward and is as defined by HL/2, [5]. The 5 GHz AP has the primary role in scheduling the transmissions in the network, allocating the resources inside its coverage area and forwarding data on behalf of the MTs. Mobility (within the coverage area of the 5 GHz AP) does not have any impact on routing decisions and connectivity with the 5 GHz AP is considered to be guaranteed for all MTs. Nevertheless, resource availability at 5 GHz is a major issue as the number of users increases and becomes necessary to offload the traffic at 5 GHz.

At 60 GHz, the communication range can be very short, depending mainly on whether an obstacle (i.e. wall, body) is present between the transmitter and the receiver. Thanks to adaptive modulation, higher transmission rates can be achieved over shorter distances. At the same time, user and environment mobility make the already vulnerable 60 GHz links unstable, further increasing the probability of data losses in the constructed paths. CANA exploits the presence of the 5 GHz AP to temper some of the disadvantages and inefficiencies of the ad-hoc networking paradigm.

The 5 GHz AP defines the paths in CANA (*BroadWay Routing*) relying on the information provided by the *Neighborhood Discovery* (ND) process.

The ND process provides information about the 60 GHz topology to the 5 GHz AP by discovering the directly reachable neighbors (one-hop away) of all MTs at 60 GHz inside the HL/2 cell and measuring the quality of the corresponding links. Every MT and the 60 GHz AP participate in ND by exchanging *hello* messages and maintain neighborhood information in the form of a list containing the neighbors and the status of the corresponding links, [5]. This information is sent to the 5 GH AP, which is responsible for the route selection.

The 5 GHz AP decides when ND should be performed. It may be done periodically or be event-driven based on several criteria such as: the available bandwidth at 5 GHz, the density of users inside the 5 GHz cell, the number of new users in the system, the detected link breakages at 60 GHz and time elapsed since the last ND process. The 5 GHz AP sends a broadcast message to inform all MTs inside its coverage area indicating the 60 GHz frequency channel that is used for ND, the time instant at which this procedure is initiated and the transmission schedule of the hello messages.

The frequency channel used for ND is the same as that used by the 60 GHz AP (since the latter also participates in the ND process). Since the MTs may be assigned a different frequency channel when constructing a communication path at 60 GHz, the link state information obtained during the ND process is an approximation (considered to be a good one) of the frequency channel actually used.

The MTs and the 60 GHz AP exchange hello messages in sequential time slots according to a time schedule sent in a message by the 5 GHz AP and based on their MAC IDs, in order to determine their one-hop away neighbors and construct their *link state tables*. After receiving its neighbors' hello messages, a MT and the 60 GHz AP can determine the state of each link with their one-hop away neighbors by measuring the signal-to-noise ratio provided by the physical layer. Depending on the measured link state, different transmission rates may be achieved.

At the end, the MTs forward the collected information to the 5 GHz AP. The 5 GHz AP schedules the transmission of the MTs' link state tables by reserving bandwidth directly after the end of the exchange of the hello messages, similarly to the standard, [3]; the only difference is that MTs do not request for resources before sending their link state tables.

The 5 GHz AP makes routing decisions based on information collected during the ND process. This information is stored (ND_table) and is updated at the end of ND. The 5 GHz AP manages all resource requests from the MTs inside the HL/2 cell by looking up the ND_table and establishing connections either at 5 GHz or at 60 GHz. The involved MTs are assigned the appropriate roles to support these connections. The connections at 5 GHz are more reliable while the 60 GHz links can offer substantially higher rates. Moreover, the availability of the 5 GHz bandwidth is limited in hotspots and consequently paths at 60 GHz will have to be used. The 5 GHz AP selects a path considering the associated link states at 60 GHz. Other quality metrics such as the remaining battery lifetime of the involved MTs and the fact that a CH or a FN consumes more energy may also be considered.

CANA imposes modifications to the existing HL/2 protocol stack, [3]. New modules are required to be added and algorithms to be included for the fine system operation. The particular layers that need to be enhanced are the *Data Link Control* (DLC) layer, which will be referred to as *CANA-DLC,* and the *Service Specific Convergence Sublayer* (SSCS), which will be referred to as *CANA-SSCS*. Additionally, a new entity (represented as a layer) is added for the efficient communication between nodes considering that *Ethernet* is the upper layer. This entity is called the *Node Communication Entity* (NCE) and it can be seen in Figure 2.

The required modules of CANA are shown in Figure 2 (referring to the enhanced protocol stack for the AP case). NCE's role is to communicate information between the AP and the MTs through *peer-to-peer* (prtpr) messages. This information corresponds to control messages that are forwarded through the *User Plane*. The corresponding module is named *Message Handler* (MH) and is located in NCE (C*ontrol Plane*).

The modules are represented as ellipses, the tables that contain information are represented as rectangulars and the depicted arrows correspond to the information flow between modules. Messages between different devices are represented with large arrows (prtpr messages and ND messages).

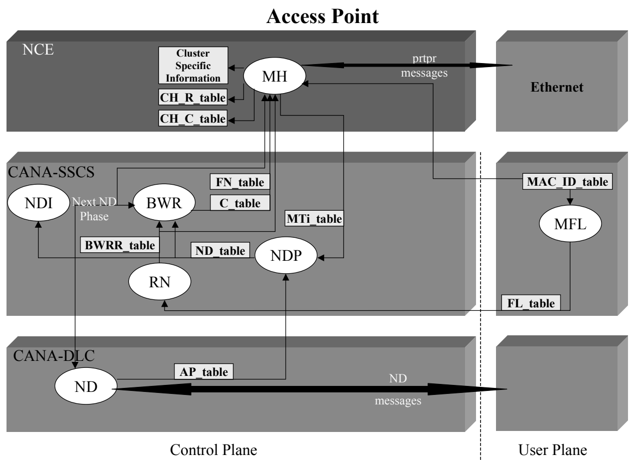

Figure 2: CANA modifications to the standard HL/2 protocol stack (at the Access Point)

The modules and their input/output are the following: 1) *Neighborhood Discovery* (ND): discovers the connectivity between nodes at 60 GHz, output: *AP_table* (*MTi_table* for each of the MTs); 2) *Monitor Flows* (MFL): monitoring of the resources for a data session, input: *MAC_ID_table*, output: *FL_table*; 3) *Resource Needs* (RN): estimation of the resources for a data session, input: *FL_table*, output: *BWRR_table*; 4) *Neighborhood Discovery Processing* (NDP): merging of ND information, input: *AP_table* plus *MTi_tables*, output: *ND_table*; 5) *Neighborhood Discovery*

Initiator (NDI): decides on the next ND phase, input *ND_table*, output: *Next ND Phase*; 6) *BroadWay Routing* (BWR): cluster and routing information, input: *ND_table* and *BWRR_table*, output: *C_table*, *FN_table*; 7) *Message Handler* (MH): responsible to send/receive information to the MTs, input: *C_table* and *FN_table*, output: *CH_C_table*, *CH_R_table*, *Cluster Specific Information* and *prtpr* messages.
The MT case is just a simplified version since it does not include any modules regarding the routing functionality (BWR).

IV. PERFORMANCE ISSUES OF CANA

The ND process constitutes the main control overhead for CANA since it requires that the system remains inactive until it is completed and for this reason it should not be executed frequently. On the other hand, this process is mandatory to be executed as it provides useful information for the establishment of ad-hoc paths. The overhead induced by the messages required to establish the paths at 60 GHz is lower and has not been taken into account for our study.
A cell of 100mX100m with 50 moving MTs has been simulated in ns-2, [6], in order to calculate the overhead of the ND process. Simulations were run for 300sec. The results were averaged over 5 runs for each scenario. Estimations of the length of the required hello messages and link state tables were made. Two different communication levels ℓ were considered based on the distance between two MTs, one for 6m and another for 15m. Two MTs that are *d* meters apart can establish a level ℓ communication as long as $0.8\ell \leq d \leq 1.2\ell$. A sequence of *n* MTs each of which is away from the preceding MT by some distance in $(0.8\ell, 1.2\ell)$ is said to form a level ℓ path of length *(n-1)* hops. It has been shown that lower communication distances may provide under different modulation techniques higher data rates, [7]. For this reason, 15m-paths are referred to as low-rate paths, whereas 6m-paths correspond to higher rates.
Mobility has been modeled using the *random waypoint model*. Each MT starts its journey from a random location and moves toward a random destination at a randomly chosen speed v (uniformly distributed between 0 and v_{max} (in m/sec), where $v_{max} \in \{1, 3, 5, 10, 15, 20\}$). Once the destination is reached, another random destination is targeted after a pause. In indoor applications, no high MT speeds (more than 3 m/sec) are expected. Nevertheless, in low-power transmissions the attenuation is higher and more vulnerable to indoor environments (where signals would have to penetrate obstacles to reach a destination). Thus, higher MT speeds have been used to illustrate the dynamic nature of short-range multi-hop network employed as well as dynamic environments induced by the propagation characteristics of 60 GHz. For the same reason, all results that are presented here correspond to a pause time of 0sec.

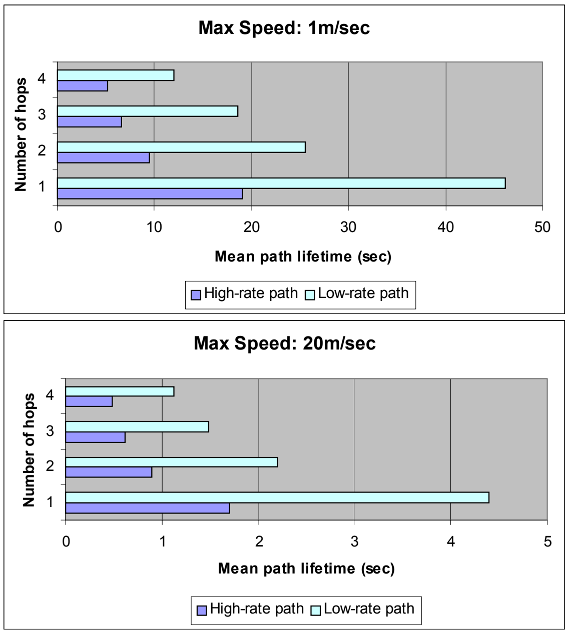

Figure 3: Mean path lifetime versus the number of hops

Figure 3 illustrates the mean path lifetime of the two communication levels (high-rate and low-rate) versus the number of their hops for the case of maximum speed of 1m/sec and 20m/sec. Although shorter distances may allow for higher rates, the shorter-range paths are more vulnerable to link failures. In high speeds (20m/sec), the mean path lifetime decreases by a factor of 10, while it is observed that the highest percentage of decrease in the mean path lifetime occurs between the first and the second hop of a path.
In Figures 4 and 5, the dependence of the overhead of the ND process from the number of hops that constitute a path, the number of MTs inside the cell, the different communication levels and mobility is shown. The ND overhead is defined as the fraction of time during which ND is performed (including the required switching time to the frequency channel of ND, [2]). The number of MTs inside a cell affects the ND overhead since it affects its duration. We assume that ND is periodically performed with such a period that more than 90% of the calculated paths do not break between two consecutive NDs for the specific speed and communication level.
More overhead is required to maintain 90% of the paths in case of more hops (due to their shorter lifetime) or when the speed increases (due to the higher probability of a link failure). Although the lifetime of multi-hop paths is low, a large amount of information can be sent over them, since the 60 GHz frequency band can support very high bit rates. To establish these high transmission rate paths, CANA needs to update the ND information. The periodicity of the ND process is adjusted (so is the induced overhead) according to the supported communication level (transmission rate) and mobility (dynamic nature of the 60 GHz environment).

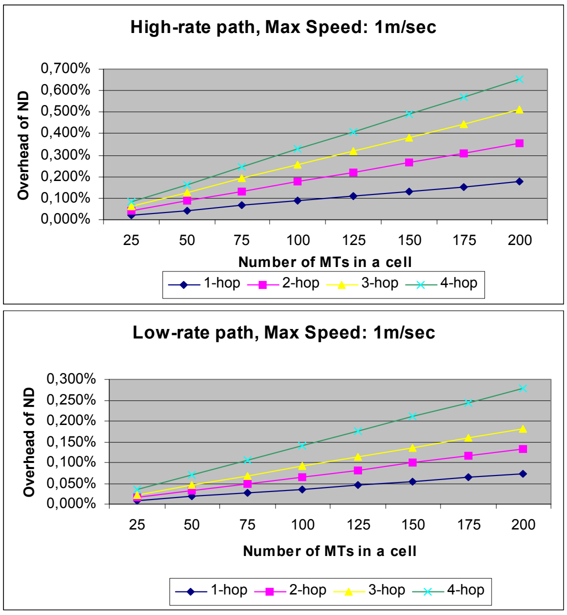

Figure 4: The overhead of ND versus the number of MTs inside a cell (for paths consisting of different number of hops)

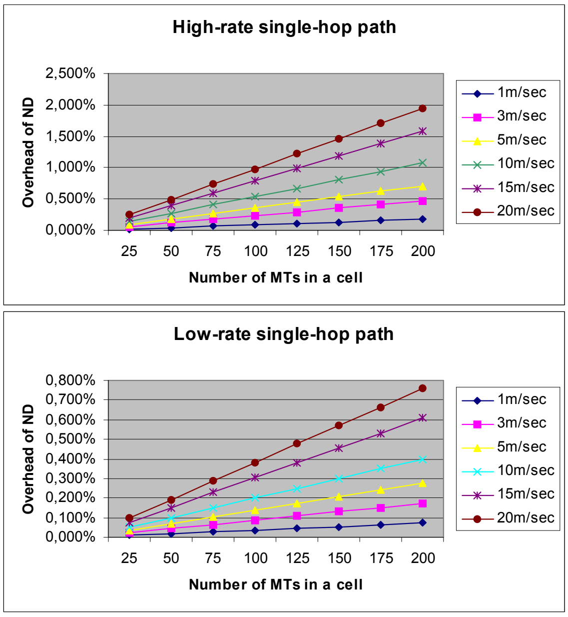

Figure 5: The overhead of ND versus mobility (for paths consisting of different number of hops)

In hotspots, where traffic needs are high and the number of users is increased, there is always the need for extra capacity. It is shown that even in the worst case, the ND overhead to support short-range paths that provide high bit rates does not exceed 7%. Consequently, the BWR algorithm decides between the offloading capability of shorter-range, multi-hop paths and the increased induced ND overhead based on the traffic needs. In addition, the effect of the different roles employed at the MTs when operating at 60 GHz should be taken into account to make efficient routing decisions.

V. CONCLUSIONS

Future trends of networking applications impose the need for enhanced infrastructure-based WLANs to meet high traffic needs in dense populated areas. The requirements for high capacity inside WLAN cells introduce the potentially beneficial use of the employment of short-range, multi-hop networks. CANA provides the means for integrating a second (ad hoc) mode of operation using the 60 GHz frequency band inside the 5 GHz traditional centralized HiperLAN/2, which is shown to provide potential for higher capacity at low overhead cost. This paper describes the enhancements that CANA imposes to standard HiperLAN/2 protocol stack in order to support the dual mode of operation. Among the modules and algorithms of CANA, Neighborhood Discovery (ND) constitutes the main control overhead of the system and may be executed based on the network characteristics (traffic requirements, density of MTs). Routing decisions should always take into account the impact of the different roles in the system's efficiency.

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