A Dual-Band HiperLAN/2-based Architecture for Indoor Hotspot Applications

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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 system 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 described as a means to efficiently support multimedia applications that require very high bit rates in low mobility environments; several ad-hoc specific functionalities are included such as *neighborhood discovery*, *clustering* and *route selection*. BroadWay introduces modifications to the MAC of HiperLAN/2 regarding new messages and framing considerations at both frequency bands to cater for the new requirements imposed by the dual mode of operation.**

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.

In case the number of users and traffic needs are high (hotspots), Wireless Local Area Networks (WLANs) appear to be a good candidate for connecting Mobile Terminals (MTs) to the Internet via the Access Point (AP). These networks provide for the extension of the fixed network infrastructure and the support of data rates at low cost but the AP that controls the single-hop transmissions inside its coverage area (cell) may always be a throughput bottleneck for the local network. Current WLANs do not scale to high data rates and increased number of users – as the growth of the Internet would require – due to the wireless data rate limitations. Ad-hoc networks have recently been considered to provide for higher in-cell capacity and low power consumption [2], [3]. Ad-hoc networks have been introduced as a network solution in emergency cases, distributing the necessary functionalities of accessing the channel and routing among the MTs and typically involving multi-hop communication without the need for a coordinating node (such as the AP) [4]. They allow for direct communication between two MTs but the need for a higher node complexity, the challenges imposed by the applied distributed routing algorithms, the great impact of mobility and the lack of Quality of Service (QoS) may make the ad-hoc networks unsuitable for meeting future user requirements.

The described Centralized Ad-hoc Network Architecture (CANA), in terms of system innovation, proposes a scalable network architecture that is based on current 5 GHz WLAN technologies equipped with extensions in the 60 GHz frequency band and can be seen beyond 3G scenarios. CANA provides a hybrid dual frequency system to offload the 5 GHz band in high-density areas (in terms of users and data traffic) taking advantage of the ad-hoc networking concept. The central control of the existing infrastructure provides the necessary means in order to establish multi-hop connections inside a cell. In CANA, the disadvantages of ad-hoc networks are suppressed while, at the same time, higher in-cell capacity is achieved.

In the following section, CANA and the induced dual mode of operation are described. In section III, the processes required to support routing functionality into the new environment are depicted while, in section IV, the paper is concluded.

II. CANA: Dual Mode of Operation

A. Motivation

The employment of the ad-hoc networking paradigm instead of infrastructure-based WLANs has been motivated by the need to support high-rate applications, the capacity requirements in hotspots and the appeal of direct peer-to-peer communication between two MTs. It is basically introduced by reducing the transmission power of the MTs to decrease the transmission range and by allowing for peer-to-peer and multi-hop communication.

There are several potential benefits by reducing the transmission range. First, the energy efficiency is improved and modulation schemes achieving higher data transmission rates can be employed. Besides, spatial reuse is potentially increased since interference is limited and more concurrent transmissions may take place. These shorter-range, multi-hop, lower-power transmissions can potentially provide for increased capacity (through spatial frequency reuse and higher data rates), increased coverage (by extending coverage away from the vicinity of the AP through multi-hop paths) and decreased power consumption.

On the other hand, there are always some drawbacks in replacing the cellular networking paradigm by shorter-range, multi-hop paths. Most of the traffic is destined to the AP and, hence, the channel around it becomes a bottleneck, limiting the throughput performance of the multi-hop network to even below that of the pure cellular network [3]. In addition, in low-density areas connectivity is not guaranteed questioning the feasibility of shorter-range, multi-hop paths. At the same time, mobility affects such paths more severely and QoS support becomes more difficult. Furthermore, ad-hoc routing protocols are more complex and induce inherent deficiencies.

CANA has been proposed to efficiently take advantage of the ad-hoc networking paradigm inside infrastructure-based WLANs. CANA is an architecture for hotspots including private (e-home entertainment, business) and public (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), [5], 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, [6], 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 and ii) the short-range operation facilitates privacy and allows for aggressive frequency reuse.

B. Dual Mode of Operation

CANA consists of a hybrid dual frequency system based on a tight integration of HL/2 and a fully ad-hoc extension of it at 60 GHz. Thus, 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 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 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.

1) Operation at 5 GHz

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 [5].

2) Operation at 60 GHz

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). Depending on the applied modulation scheme, the constellation size and the cost of the MT, the transmission rates can reach 100-700 Mbps [7]. 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 (described below) that are all assigned by the 5 GHz AP. This distinction is based on the different functionalities that a role encompasses and not on different hardware capabilities. MT maintains its assigned role for as long as it is dictated by the 5 GHz AP or until an established path it participates in breaks. An MT can undertake only one role at a time but this role may change over time as needed.

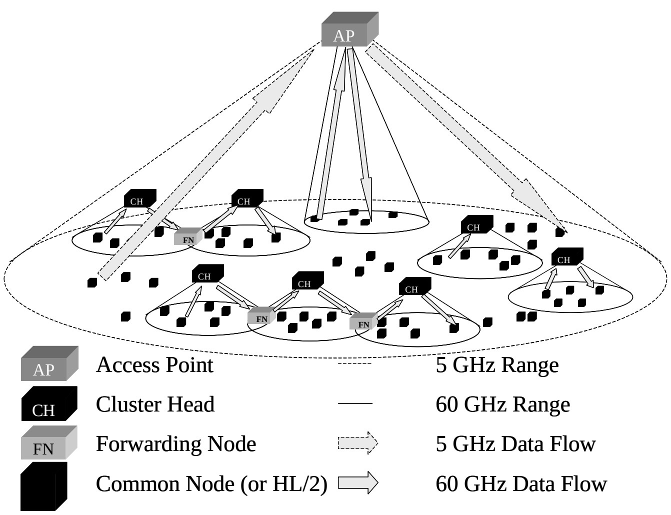

Figure 1: A time instant of CANA

a) Clusterhead (CH)

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- 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.

b) Forwarder Node (FN)

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).

c) Common Node (CN)

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.

III. Routing in 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 (wall, body) is present between the transmitter and the receiver. Thanks to adaptive modulation, higher transmission rates can be achieved over shorter distances [7]. 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 (*Route Selection*) relying on the information provided by the *Neighborhood Discovery* process.

A. Neighborhood Discovery (ND)

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 [8]. 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 [5]; the only difference is that MTs do not request for resources before sending their link state tables.

B. Route Selection

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.

The basic rules of a simple routing algorithm executed by the 5 GHz AP are stated below:

1. Whenever a resource request arrives, the 5 GHz AP accesses the ND table to determine the candidate 60 GHz paths for the source-destination pair (60 GHz connectivity check).
2. If there is connectivity at 60 GHz, the most efficient path is identified; efficiency may be defined based on metrics such as: the number of hops, the link states, the need for FNs, the present allocation of resources at 60 GHz and the kind of application to support (required bit rates).
3. (a) If there is no 5 GHz bandwidth available, the most efficient 60 GHz path identified is utilized.
   (b) If there is 5 GHz bandwidth available, it may be utilized instead of the most efficient 60 GHz path identified. Such a decision could be based on criteria such as the quality and bandwidth of the identified 60 GHz path (number of hops, need for a FN, link states, transmission rates, etc.) and the amount of unutilised 5 GHz bandwidth. If the 5 GHz bandwidth is decided to be used, the 5 GHz AP allocates 5 GHz bandwidth to establish the required connection as specified in the standard [5].
4. If there is neither 60 GHz connectivity nor 5 GHz bandwidth available, the connection cannot be established and the resource request is resubmitted in the future (rule 1).

When the route is selected, part of the associated frames is reserved for the communication [9]. For a 5 GHz communication the procedure is specified in the standard [5]. When a 60 GHz path is established, the 5 GHz AP sends new messages defining the lifetime of the path, the participants and their role in the path as well as the resources allocated for this request. The CH can allocate resources inside its cluster as well; this way, MTs can use an already established cluster. The established paths are defined to expire until the next ND process is initiated so that all MTs (and the 60 GHz AP) can participate in it. The TDMA structure of the 60 GHz frame allows for multiple collision-free paths under the control of the assigned CHs. When a 60 GHz path breakage occurs, the participating MTs switch back to the 5 GHz frequency band.

In Figure 2, the different states of a MT in CANA are illustrated.

IV. CONCLUSIONS

Present infrastructure-based WLANs need to be enhanced to accommodate the demanding emerging applications in highly dense areas. The ad-hoc networking paradigm has been considered as a means to offload the infrastructure-based WLANs and provide for extra capacity. The paper explores the challenges of such hybrid environment based on the concept of the BroadWay project and introduces an architecture (CANA) to deal with the new technology requirements.

Routing in CANA includes innovative mechanisms since it combines ad-hoc techniques and a cellular architecture. In the centralized routing scheme, the AP is responsible for making routing decisions and establishing the required paths choosing between the 5 GHz and the 60 GHz band. The neighborhood discovery process provides the information needed for the 60 GHz operation. Due to the physical characteristics of the 60 GHz band (Line-Of-Sight constraints, short transmission ranges), the users' and environment's mobility and the existing infrastructure, a dual mode of operation is designed with the 5 GHz band being the primary frequency band

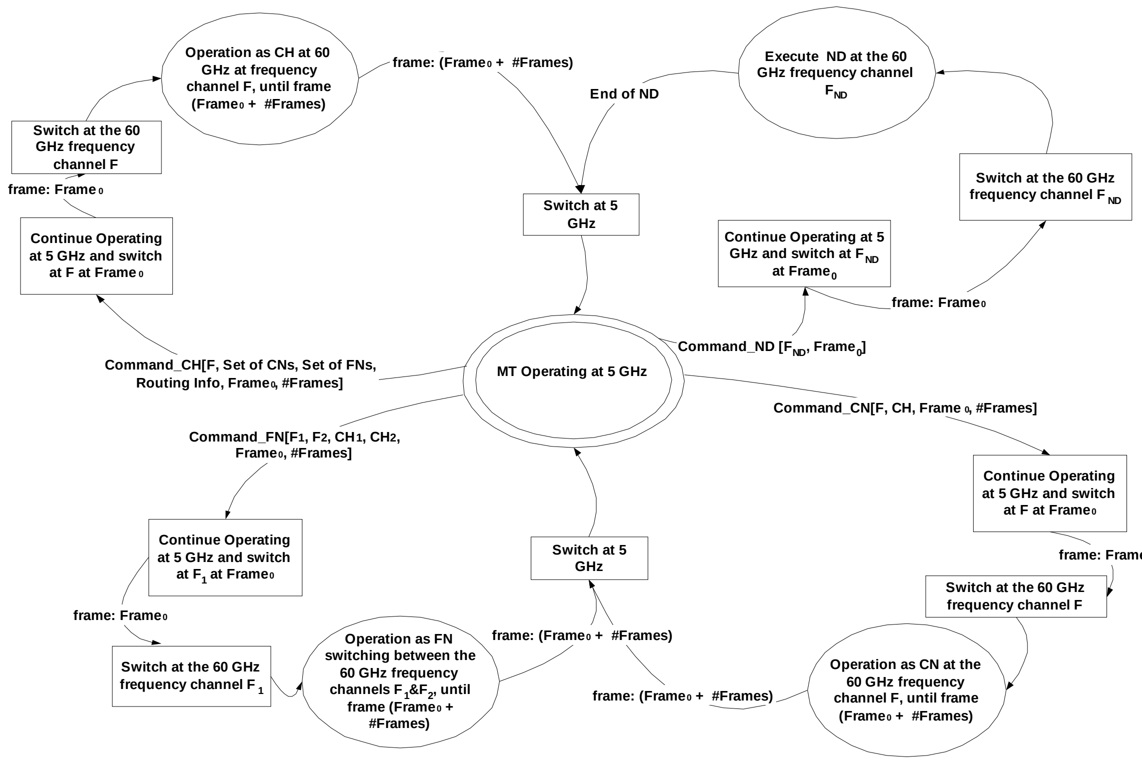

Figure 2: Different states of a MT in CANA

whereas 60 GHz channels provide for offloading the 5 GHz band and supporting higher rate applications. Thus, CANA caters for HiperLAN/2 requirements and supports high bit rate applications in hotspots at the same time.

ACKNOWLEDGEMENT

The BroadWay project (IST-2001-32686) is partly funded by the Commission of the European Community.

The partners involved in the project are the Motorola Labs France, TNO-FEL Netherlands, Intracom and the National & Kapodistrian University of Athens, Greece, IMST, IRK and Dresden University of Technology, Germany and FARRAN, Ireland.

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