HiperLAN/2 WLAN Prototype Demonstrates 40 Mbit/s Multimedia Applications with Quality of Service

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ABSTRACT

This paper presents the demonstration results of a Wireless LAN (WLAN) prototype compliant with the European ETSI BRAN HiperLAN/2 standard. The HiperLAN/2 system enables bit rates from 6 Mbit/s up to 54 Mbit/s on top of a 5GHz wireless link and its powerful MAC/DLC layer enables Quality of Service (QoS) for multimedia applications up to 40 Mbit/s.

I. INTRODUCTION

Wireless Local Area Networks (WLANs) have recently experienced a rapid development mainly due to the increase of the bandwidth they can offer, which now comes close to the capacity of a Fast Ethernet network. This evolution has enabled their deployment in two domains: office and hot spot environments. When implemented in offices they allow an easy extension of existing wired networks and facilitate their re-deployment. In hot spots, they are used by service providers to offer an easy connection to their backbone networks from public areas.

In both environments, they support the basic services usually provided by a classical LAN based on file transfers: WWW access, e-mail delivery, connections to servers, etc.

When it comes to interactive services like video conferencing, telephony or streaming video, the current WLAN technology (based on the IEEE 802.11 standard family) becomes very limited by its inability to guaranty specific quality of service to these types of applications. Such limitations hinder broadening of WLAN deployment to environments such as industrial control and home where high bit rate interactive audio and video applications are widely used.

Another approach, based on previous work made on wireless ATM, led to a new WLAN standard: HiperLAN/2, promoted by ETSI/BRAN (MMAC has issued a sister standard in Japan: HiSWANa). HiperLAN/2 embeds QoS features that enable it to go beyond the limitations of previous systems and to widen the application field of WLANs. These mechanisms include:

- Dynamic Link Adaptation (LA): modulation scheme is dynamically selected among a set of 7 different modes depending on the radio link conditions
- Power Control: radio transmission power level can be dynamically adapted to the radio link conditions
- Packet transmission scheduling: resource is allocated to applications in a fair manner according to their needs
- Flexible and powerful error control
- Low latency automatic retransmission (ARQ): lost data are quickly and efficiently retransmitted
- Forward Error Control scheme for very low delay demanding applications

HiperLAN/2 also includes a set of Convergence Layers that makes it an efficient access technology to various networks: IEEE 1394, Ethernet, ATM, UMTS, and IP.

Taking advantage of these characteristics, HiperLAN/2 is able to support QoS demanding applications such as high quality video streaming and interactive multimedia services in a wide range of environments.

II. PRESENTATION OF THE PROTOTYPE

We designed and built a full blown HiperLAN/2 prototype, from Radio Frequency to IP Convergence Layer. We had a special focus on OFDM technology and enhanced QoS mechanisms in Data Link Control and upper layers.

In this context, we have developed advanced synchronisation, equalisation and decoding techniques dedicated to 5GHz radio transmission; an efficient scheduling policy; a dynamic Link Adaptation mechanism in addition to a real-time ARQ and an IP Convergence Layer based on traffic contracts and flow classification.

With this laboratory prototype, we can illustrate the high level of Quality of Service supported by HiperLAN/2, the only available WLAN standard (with HiSWANa) capable of achieving this level of performance. We also demonstrate that there is no technical issue that prevents HiperLAN/2 from industrialisation.

A. HiperLAN/2 standard

The HiperLAN/2 standard (H/2) defines Physical (PHY), Data Link Control (DLC) layers as well as a set of core network specific Convergence Layers (CL). Figure 1 depicts the H/2 protocol reference model.

Physical layer [1] is based on OFDM technology and signal is sent on a unique 20 MHz frequency channel at 5GHz. Several modulations and coding rates provide different physical throughput and error robustness levels. Medium access is based on a dynamic Time Division Multiple Access-Time Division Duplex (TDMA-TDD) scheme with a fixed duration frame (2 ms).

At DLC level [2][3], data transfers are connection oriented and resource allocation is centralised into a single point called the Access Point (AP). User data is transported in 54-octet PDUs containing 48-octet payload and control data is conveyed in shorter 9-octet PDUs. The standard defines different error control modes including an unacknowledged mode, an acknowledged mode using an Automatic Repeat-Request protocol (ARQ) and a Forward Error Control (FEC) mode.

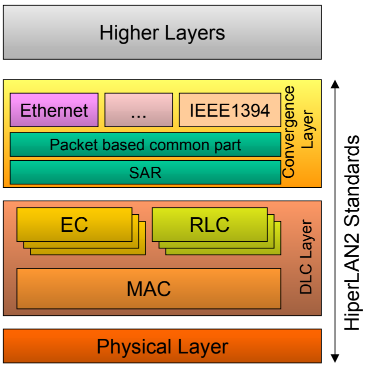


Figure 1: the H/2 protocols' reference model

B. An Implementation of HiperLAN/2 standard

The HiperLAN/2 prototype has been implemented on a hardware and software programmable platform enclosed in a CompactPCI rack (see Figure 2). The system is constituted of four boards: Radio Frequency (RF), Intermediate Frequency (IF), baseband (C-OFDM) and DLC.

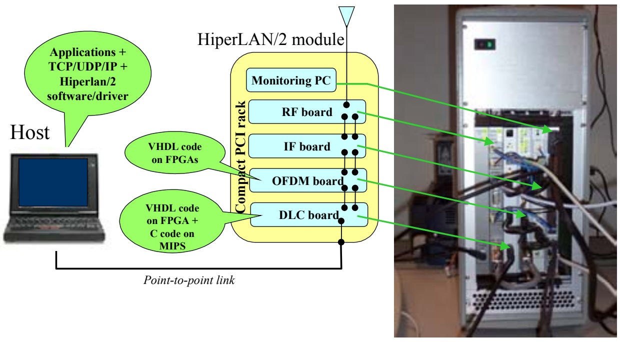


Figure 2: H/2 prototype

The open nature of the ETSI standard and the flexibility of the prototype platform enable the implementation of a set of proprietary algorithms for both the PHY and DLC layers of HiperLAN/2. From a system architecture point of view, a very tight coupling between DLC and PHY has been implemented so that efficient RRC (Radio Resource Control) mechanisms could be designed. In addition, an innovative QoS aware IP Convergence Layer, based on traffic contracts and flow classification, has been designed for IP based applications.

C. Boards description

The RF board supports all the frequency channels defined by the standard in the 5GHz band and provides a fully programmable power level (max. output power is +15 dBm).
The IF board allows conversion of the analog OFDM signal at 140MHz.
The C-OFDM board is constituted of 5 high-speed FPGAs programmed in VHDL language. ADC and DAC are operating at 80 MHz.
The DLC board is organised around a MIPS processor clocked at 400MHz with large internal memory cache. Attached to the processor, an FPGA implements the interface with the C-OFDM board and an Ethernet controller performs the interface with the upper layer. This latter embeds a subset of segmentation/re-assembly tasks required by the IP Convergence Layer. All DLC layer functions have been developed in C code. For performance reasons, real-time tasks run on the MIPS processor without support of any operating system while signalling functions run on the host processor.

D. Features of the different layers

PHY layer

The PHY layer of the prototype realises the following functions: modulation/demodulation, DLC transmit and receive interface, and up/down conversion from baseband to 5GHz RF.
Regarding the modulation, the main functions are scrambling, encoding, interleaving, OFDM modulation (IFFT) and Up conversion.
Demodulation is the most complex process: down conversion, OFDM demodulation (FFT) with channel estimation (including a noise reduction filtering) and equalisation, demapping, de-interleaving and Viterbi decoding. On top of these functions, the whole synchronisation process is performed in time and frequency domains with coarse and fine tuning. In a HiperLAN/2 system, the modulated signal is transmitted in bursts preceded by known preambles that are used for rapid acquisition and synchronisation, even in the presence of multipath and other channel impairments.
In addition, a phase noise compensation unit has been implemented in order to cope with long packet transmission, using the 4 pilots included in each data burst.

DLC layer

The Access Point implements a dynamic packet scheduler based on several Weighting Fair Queuing algorithms that allocate resource to DLC connections. This scheduler is able to manage Constant Bit Rate (CBR) as well as Best Effort services. For every connection, radio resources are allocated in each frame by taking into account connection queue state, radio channel condition (cf. Link Adaptation below) and parameters negotiated at connection setup such as throughput or ARQ window size. DownLink (DL) and UpLink (UL) connections are processed in a similar way. For UL connections, terminals communicate the state of their connections queues by using Resource Requests.
The dynamic Link Adaptation (LA) algorithm is based on signal-to-noise ratio (C/I) measurements performed by both AP and terminal. The same modulation is applied to

every connection dedicated to a particular terminal. Signalling PDUs are encoded systematically in BPSK ½ to insure a maximum robustness to errors.

ARQ implementation allows reaching a 4ms Round Trip Time in most cases and thus offers a low delay service to higher layers. A discard mechanism is also implemented but is not enabled in the demonstrator. Resources used to transmit feedback messages and to retransmit erroneous PDUs are dynamically allocated by the scheduler in the AP.

Convergence Layer

IP flow classification is performed through a hashing table that maps IP datagrams to DLC connections using the quadruplet (IP source, IP port source, IP destination, IP port destination). However, as applications do not always use a fixed port number, some jokers can replace one of these fields. Moreover, several IP flows can be aggregated into a given DLC connection.

II. PRESENTATION OF THE DEMONSTRATION

A. One Access Point (AP) and two Mobile Terminals (MTs)

This prototype has been integrated into a demonstration platform of one AP and two terminals supporting a mix of high demanding applications.

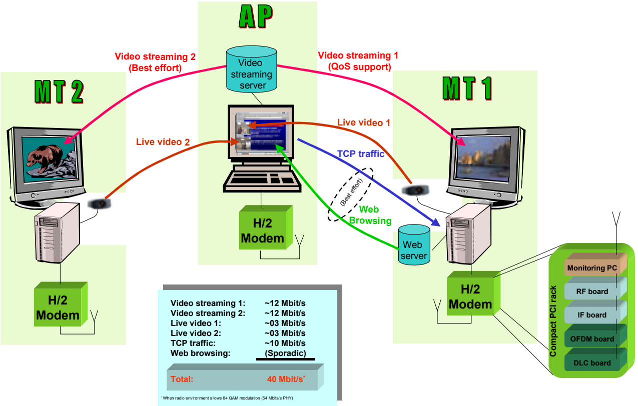
Figure 3 summarises the demonstration scenario and applications data flows transmitted over a single 20 MHz bandwidth channel (the carrier frequency can be selected from 5.18 GHz up to 5.7 GHz). Transmitted output power can be adjusted from –10 dBm up to 15 dBm according to the distance between AP and MTs (from a few meters up to several tens of meters).

B. 40 Mbit/s simultaneous multimedia applications in full duplex.

Thanks to this scenario we can demonstrate successful simultaneous operation of following streams (when the 64-QAM ¾ PHY mode enabling 54Mbit/s on top of PHY layer is employed):

- 2 downlink DVD MPEG2 videos (~10 Mbit/s each) transmitted over plain UDP without flow control at application level;
- 2 uplink live H.261 video captures (3 Mbit/s each);
- Uplink Web browsing (TCP);
- Downlink TCP background traffic (13 Mbit/s).

Each application flow is mapped onto a dedicated DLC connection. MPEG/2 video played on MT1 is transported over a CBR connection whereas the second MPEG/2 flow sent to MT2 is handled in Best Effort mode. Both H.261 live video captures are transported over CBR connections. Finally, web browsing and generated TCP traffic use Best Effort connections. Each connection is set up with acknowledged error control mode, using an ARQ window size of 256 PDUs for MPEG2 and Best Effort connections, and 64 PDUs for H.261 data flows. TCP traffic generated in downlink allows to completely fill the radio cell's capacity and to reach a maximum total throughput of about 40Mbit/s. This configuration highlights the high Quality of Service level the system is able to offer to the final user whatever the radio link conditions are.



Video streaming 1:	~12 Mbit/s
Video streaming 2:	~12 Mbit/s
Live video 1:	~03 Mbit/s
Live video 2:	~03 Mbit/s
TCP traffic:	~10 Mbit/s
Web browsing:	(Sporadic)
Total:	40 Mbit/s*

* When radio environment allows 64 QAM modulation (54 Mbits/s PHY)

Figure 3: Demonstration platform

III. MONITORING TOOLS

Monitoring tools have been added in order to dynamically measure and display main relevant parameters.

A. Monitoring of PHY layer parameters

For configuration, debugging and research purposes, following parameters can be retrieved from the modem and monitored permanently: transmit and receive frame samples, channel estimation in time and frequency domains, constellation before and after equalisation (with Error Vector Modulation value) and Bit-Error-Rate before and after Viterbi decoder.

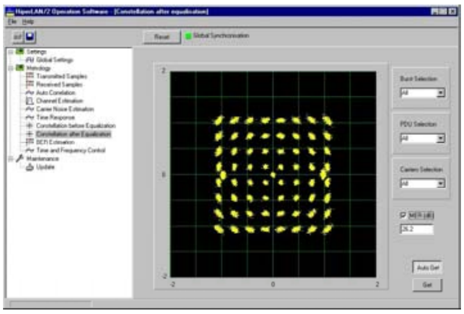


Figure 4: Constellation after equalisation (64-QAM ¾ mode)

Display of the constellation after equalisation enables to follow the modulation (PHY mode) selected by the link adaptation procedure matching the radio link propagation conditions (see Figure 4 and Figure 8).

B. Monitoring of DLC layer parameters

Again for configuration, debugging and research purposes, some DLC parameters can be retrieved from the different DLC boards and displayed on a centralised tool. Namely, the available throughput for each connection enables to follow in real time (see Figure 5) how the system adapts and shares the total resources between all applications. Resources allocated for signalling and Packet Error Rate can also be tracked to study the behaviour of the algorithms used for resource allocation and retransmission.

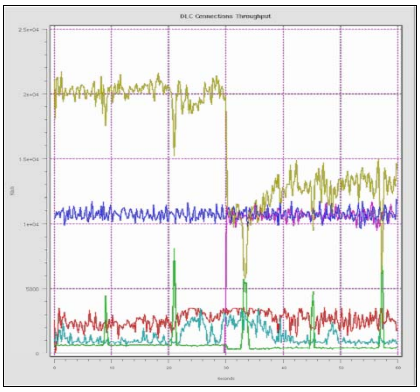


Figure 5: DLC monitoring tool snapshot

IV. QUALITY OF SERVICE vs BEST EFFORT

A. QoS and dynamic bandwidth sharing

Thanks to data flow classification and efficient resource scheduling, QoS contracts are preserved despite global throughput variations.

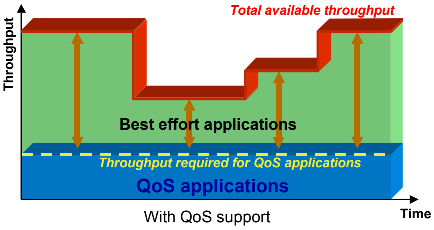


Figure 6: Fair bandwidth sharing with QoS support

The total available throughput is fairly allocated to applications with respect to their requirements: connections with QoS are allocated with the highest priority to fit their QoS contracts. The remaining bandwidth is dynamically shared among Best Effort streams proportionally to their respective weight that is defined upon connection setup. When total available throughput decreases (see Figure 6), the system is still able to guaranty QoS applications contracts by reducing resources allocated to Best Effort streams in a way proportional to their weight.

By comparison, a Best-Effort-based system is not able to differentiate among application requirements, and QoS demanding applications are equally affected by capacity reduction due to propagation degradation (see Figure 7).

B. Radio Interference example

Among the two downlink MPEG2 videos (~10 Mbit/s each), one is defined as “QoS movie” and the other one as “Best-Effort movie”. When radio propagation conditions change, the link adaptation algorithm selects a more adapted physical mode for the affected terminal. For instance, if conditions become harsher, the system automatically switches to a more robust PHY mode as illustrated in Figure 8.

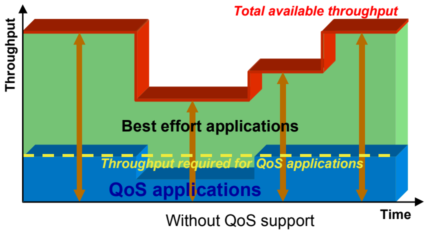


Figure 7: Bandwidth sharing without QoS support

The number of OFDM symbols needed to encode the same amount of data required by QoS applications increases, and thus induces a reduction of the bandwidth available for Best Effort connections as shown on Figure 6. The Best Effort connection with the lowest weight (DL TCP traffic in our demonstration) is the most impacted flow while throughput of connections with CBR contracts remains stable as shown in Figure 9. Effects on the Best Effort video connection become visible when radio conditions become a step harsher since its weight is greater than those of other Best Effort connections.

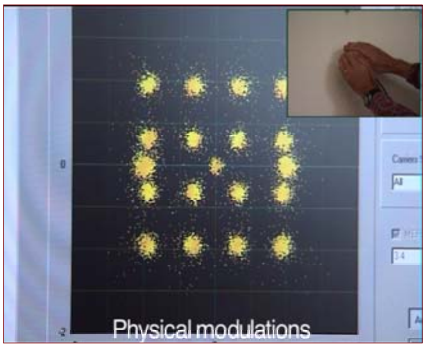


Figure 8: Link Adaptation effect in case of interference

Once perturbation ends, the latter connection tries to catch up with delay: data produced at constant bit rate by the MPEG/2 source, accumulated in the input DLC queue during radio conditions degradation are finally transmitted. It is also to be noted that TCP has adapted its activity to the throughput actually provided by the DLC. When available bandwidth recovers, the video connection empties its queue before TCP re-adapts to the new throughput provided.

C. Effect on applications

In such conditions, the QoS movie experiences absolutely no degradation whereas its Best Effort counterpart is al tered by stops or image artefacts due to delays and losses. As mentioned above, TCP traffic adapts well to the bandwidth provided as long as it remains above zero. ARQ guaranties that no packets are lost, which dramatically improves TCP performances on such an error-prone link.

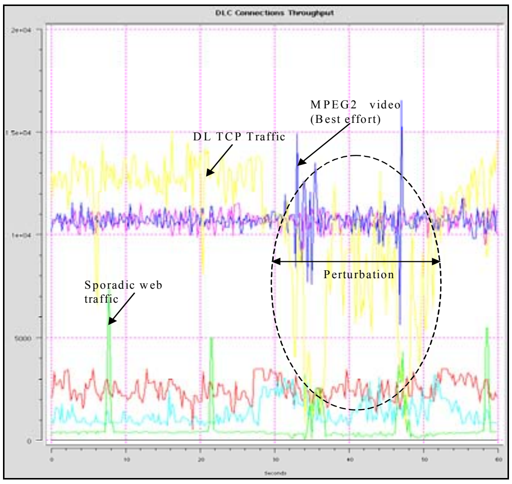


Figure 9: Radio perturbation and QoS support

V. HIPERLAN/2 GLOBAL PERFORMANCES

Some measurements (Figure 10) have been performed using a hardware radio channel fading emulator (TAS 4500), on a pseudo-BRAN type-C channel [4] setup with following parameters:

Pseudo-BRAN C channel	
Path1	0ns /-3.3dB
Path2	50ns / 0dB
Path3	80ns / -0.9dB
Path4	180ns / -1.5dB
Path5	230ns / -3.0dB
Path6	600ns / -9.4dB
Ricean factor K	0 for all paths
Doppler	10Hz, (~2km/h at 5GHz)

We found a difference in average of less than 0.5~1dB in comparison with theoretical results on AWGN channel.

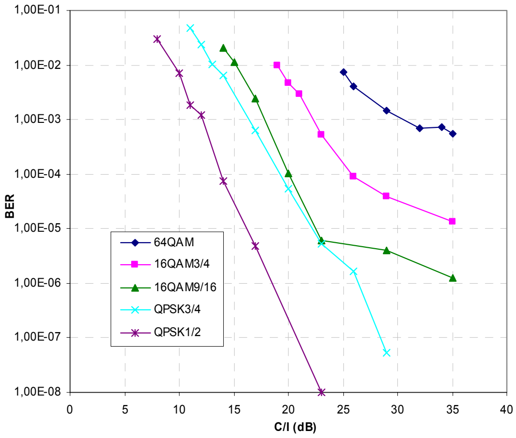


Figure 10: BER versus C/I measurements

At DLC level (Figure 11), the following parameters have been used to open a single downlink Best Effort connection in order to measure the system goodput for different signal-to-noise ratios (C/I). The goodput is defined as the maximum throughput without any packet loss at IP level.

- No discard
- ARQ window size: 512
- FIFO size: 16384 PDUs (786Ko)

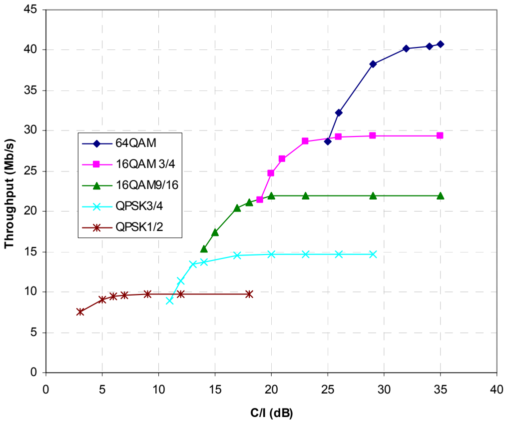


Figure 11: Maximum goodput measurements

VI. CONCLUSIONS

We have shown with this prototype that a HiperLAN/2-compliant system is actually able to offer a total bandwidth of 40 Mbit/s to applications. Its QoS capabilities make it able to fairly mix various types of application data, from high demanding data streams like MPEG2 or live video to typical bursty traffic like TCP in real radio conditions.

VII. ACKNOWLEDGEMENTS

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