Performance Evaluation of a HiperLAN/2 WLAN Prototype

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Abstract: *This paper presents the performance evaluation of a wireless LAN (WLAN) prototype compliant with the European ETSI BRAN HiperLAN/2 standard. The prototype demonstrates the feasibility of a wireless transmission at 5 GHz in 64-QAM allowing a maximum bit rate of 54 Mbit/s on top of the physical layer. Thanks to a powerful DLC layer, the modem is able to provide up to 42 Mbit/s at the user level with support of quality of service (QoS) such as constant bit rate connections. In this paper, we focus on the performance of the physical layer in terms of bit error rate (BER) and packet error rate (PER) in realistic transmission conditions and with multimedia applications. According to these results, we anticipate possible deployment of such WLAN systems as well as their future applications.*

Keywords: Wireless LAN, HiperLAN/2 prototype, BER and PER performance, 5 GHz OFDM transmission.

1. INTRODUCTION

By combining high bit rates and mobility, Wireless LANs appear as a very promising technology. WLAN systems aim at providing nomadic users with a wireless access to core networks in a business, industrial, public or home environment. In order to cope with the congestion in the 2.4 GHz band used by WiFi and also to provide higher bit rates, three standards relying on the OFDM technology in the 5 GHz band have been released, namely the IEEE802.11a [1], the MMAC HiSWANa [2] and the ETSI/BRAN HiperLAN/2 [3], [4] standards where HiSWANa and HiperLAN/2 are two companion standards. The IEEE802.11a and HiperLAN/2 standards rely on two compatible physical layers which feature a scalable transmission rate from 6 Mbit/s up to 54 Mbit/s depending on radio channel condition [5]. The table 1 summarizes the available physical modes for HiperLAN/2. These two standards mostly differ in terms of layer 2 protocols. The HiperLAN/2 standard is based on a centralized connection-oriented TDMA/TDD scheme which is particularly well suited for providing QoS support to user applications. For that reason, the HiperLAN/2 system appears as an alternative to the IEEE802.11a for applications where QoS is essential such as video streaming and real-time applications.

In order to demonstrate the relevance of the HiperLAN/2 key features, we developed a hardware prototype implementing the WLAN European standard. The goal was twofold: to show that HiperLAN/2 is able to provide high bit rates at the user level and to demonstrate the suitability of HiperLAN/2 to implement QoS.

PHY Mode	Physical layer bit rate
BPSK ½	6 Mbit/s
BPSK ¾	9 Mbit/s
QPSK ½	12 Mbit/s
QPSK ¾	18 Mbit/s
16QAM 9/16	27 Mbit/s
16QAM ¾	36 Mbit/s
64QAM ¾	54 Mbit/s

Table 1: HiperLAN/2 physical modes.

This paper concentrates on the characterization of the HiperLAN/2 physical layer. The modem performance is evaluated in terms of bit error rate (BER) and packet error rate (PER) which is more relevant for the DLC layer. The BER performance of the HiperLAN/2 prototype is evaluated in two different cases: with a 5 GHz radio transmission in indoor and outdoor conditions and using a channel emulator to provide figures on reference channels. In order to anticipate the potential advantages and applications of future HiperLAN/2 products, the PER performance is derived from data that simulate typical multimedia traffic.

The paper is organized as follows: Section 2 gives a brief overview of the HiperLAN/2 prototype. In section 3, we present the prototype performance for reference channels using a channel emulator. Finally, section 4 deals with the prototype performance at 5 GHz.

2. PROTOTYPE PRESENTATION

2.1. Introduction

The HiperLAN/2 standard defines physical (PHY) and data link control (DLC) layers as well as a set of core network specific convergence layers (CL). The HiperLAN/2 protocols reference model is depicted on the figure 1.

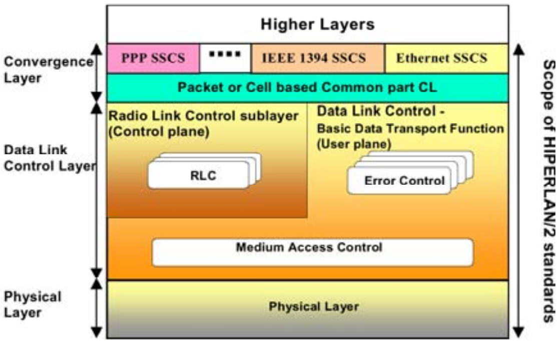

Figure 1: HiperLAN/2 protocols reference model.

According to this layer structure, the HiperLAN/2 prototype has been implemented in a CompactPCI rack, which contains RF, 140 MHz-IF, OFDM (baseband) and DLC boards. Monitoring tools have been implemented in the prototype in order to measure and display relevant parameters, which are continuously monitored. The prototype itself is illustrated on the figure 2.

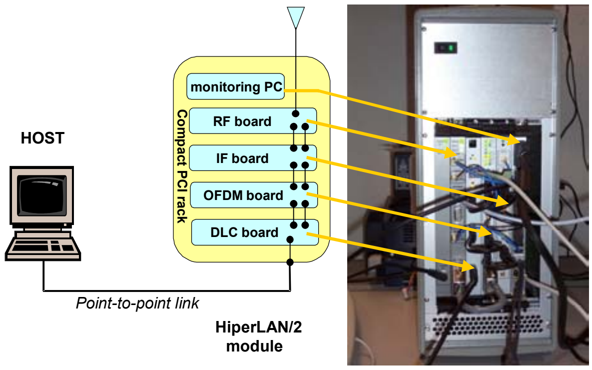

Figure 2: Prototype description.

2.2. PHY layer functions

The PHY layer of the HiperLAN/2 prototype realizes the following functions: modulation/demodulation, DLC transmit and receive interface, up/down-conversion from baseband to 5 GHz. The main functions on the modulation side are scrambling, encoding, interleaving, OFDM modulation (IFFT) and up-conversion. Demodulation is the most complex processing with down-conversion, OFDM demodulation (FFT), channel estimation (with a noise reduction filtering), equalization, de-mapping, de-interleaving and Viterbi soft-input decoding.
On top of these functions, the synchronization is performed in time and frequency with coarse and fine tuning. Besides, a phase noise compensation unit, using the 4 pilots included in each data symbol, has been implemented to cope with long packet transmission.

2.3. DLC layer functions

The DLC layer is divided into MAC (medium access control), RLC (radio link control) and EC (error control). The MAC layer implements a scheduling policy that can be either "rigid" or "elastic" depending on the quality of service required by each connection. The "rigid" or CBR (constant bit rate) scheduler guarantees a peak bit rate to the connections, whereas the "elastic" scheduler allocates when available resources to connections proportionally to their weight. This latter mode is equivalent to the best effort approach of the IEEE802.11a protocol. Error Control relies on either ARQ (automatic repeat request) or FEC (forward error correction) in an acknowledged or unacknowledged mode.

2.4. Demonstration set-up and results

Most of the prototype modules have been developed in order to cover realistic scenarios. For demonstration purposes, a single cell including one access point (AP) and two mobile terminals (MT) has been set up. In the best situation, when the mode 7 (64-QAM, R = ¾) can be used, the transmission rate on the radio link reaches 54 Mbit/s after FEC decoding. After suppression of the DLC overhead, the throughput available at the user level equals 42 Mbit/s, where IEEE802.11a is only able to provide 30 Mbit/s. The typical demonstration we implemented features the following applications running simultaneously: two 11 Mbit/s MPEG-2 movies (downlink) one in best effort mode and one in CBR mode, two 3 Mbit/s video conferences (uplink), a periodic web browsing (uplink) and a dummy random TCP traffic of 14 Mbit/s (downlink) for a total of 42 Mbit/s. The figure 3 below shows this demonstration scenario.

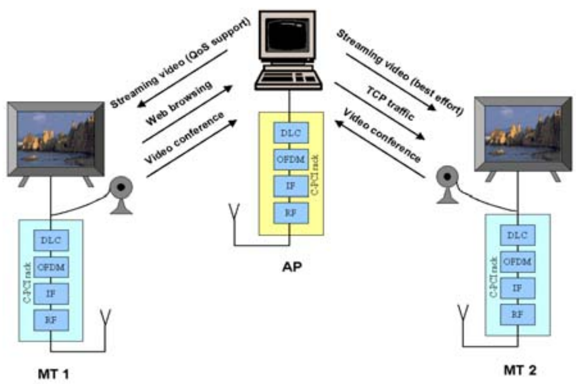

Figure 3: Demonstration scenario.

Depending on the radio propagation conditions, it is not always possible to operate in the best mode. To ensure a continuous matching between required bit rate and transmission quality, the DLC embeds a link adaptation algorithm that allows to switch automatically into a more robust mode when the propagation conditions degrade.

In these conditions, the scheduling algorithm allocates to the CBR connections more time slots in the frame while reducing those allocated to the best effort connections. When deep fades occur, the demonstration shows that the CBR movie continues to run properly while the best effort movie freezes periodically in time. This scenario clearly demonstrates the advantage of introducing the QoS as a basic requirement in the definition of a WLAN system. From this point of view, the HiperLAN/2 system is particularly well suited for QoS demanding applications.

3. PERFORMANCE ON REFERENCE CHANNELS

Our prototype enables the field test evaluation of the PHY layer performance in true scenarios at 5 GHz. However, such measurements are not suitable for comparison due to the difficulty in reproducing the propagation conditions. To provide usable figures, the performance of the prototype has been evaluated using a hardware channel emulator. With an operating frequency limited to 3 GHz, it was not possible to perform these tests on the 5 GHz RF signal. Therefore, the measurements were performed with the 140 MHz output signal of the IF board. It must be emphasized that this approach does not include the impact of RF impairments. However, the Doppler speed was set such as to reflect a 5 GHz transmission.

3.1. BER performance

BER is measured in a stand-alone mode of the PHY layer modem with an emulated DLC generating a pseudo random binary sequence (PRBS). The experimental results are provided for three modes, the mode 7 (64-QAM, R=¾, 54 Mbit/s), the mode 5 (16-QAM, R=9/16, 27 Mbit/s) and the mode 3 (QPSK, R=¾, 18 Mbit/s). Measurements have been compared with theoretical results obtained from an equivalent fixed-point simulation chain. In the following, the BER measurements were performed with a packet (burst) length of 100 OFDM symbols.

At first, and for reference only, we present the BER performance on the AWGN channel (figure 4). We found a difference in average of less than 0.5~1dB in comparison with the theoretical results. This result is satisfactory taking into account the existing inaccuracy of the C/N calibration and the hardware degradation.

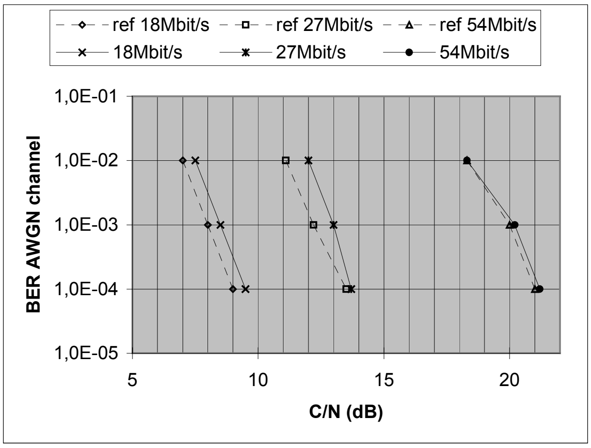

Figure 4 : BER on AWGN channel.

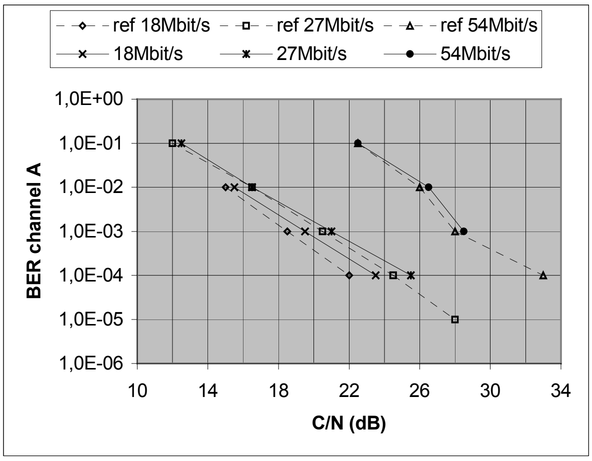

Figure 5: BER on pseudo-BRAN A channel.

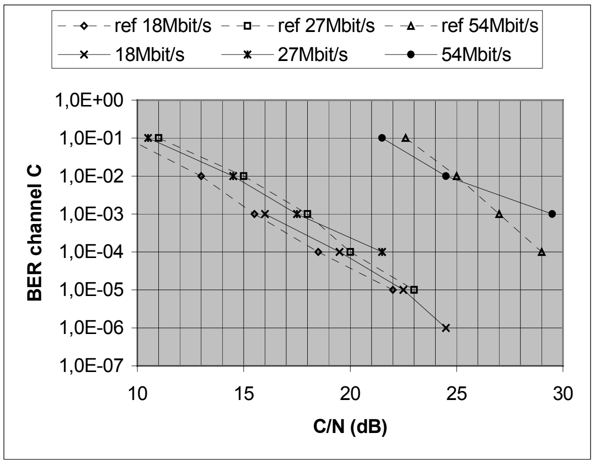

Figure 6: BER on pseudo-BRAN C channel.

The ETSI/BRAN working groups have defined some typical channel profiles for the HiperLAN/2 environment

[6]. However these channel models include in average around 20 paths while our channel emulator capability is limited to 6. Therefore, we selected the 6 most significant paths (with a trade-off between power and delay) for each channel, in order to describe "pseudo-BRAN" channels A and C (see table 2). The Doppler spread was set to reflect a mobile speed of 2 km/h at 5 GHz. The measurements were performed on the uplink with a downlink free of any interference. The corresponding results are depicted on the figures 5 and 6.

Again, we can observe a difference lower than 0.5~1 dB in average in comparison with the theoretical results. It is worth noting that the channel C (corresponding to a typical large open space environment) offers better performances than the channel A (corresponding to a typical office environment) even though it features a larger delay spread (here 600 ns versus 140 ns). Besides, we can observe that both channels are NLOS (non line of sight) and the mode 7 (64-QAM R=¾) cannot be practically used on such channels due to the very large C/N requirement to achieve a low BER.

Pseudo-BRAN A	Pseudo-BRAN C
Path1 : 0ns / 0dB	Path1 : 0ns /-3.3dB
Path2 : 10ns / -0.9dB	Path2 : 50ns / 0dB
Path3 : 20ns / -1.7dB	Path3 : 80ns / -0.9dB
Path4: 30ns / -2.6dB	Path4: 180ns / -1.5dB
Path5: 110ns / -4.7dB	Path5: 230ns / -3.0dB
Path6: 140ns / -7.3dB	Path6: 600ns / -9.4dB

Table 2: Definition of the pseudo-BRAN channels.

3.2. PER performance

The PER performance was performed following the same set-up as above (pseudo-channels A et C). However, in this case, the modem is driven by a true DLC board which emulates a multimedia-like CBR user traffic of about 11 Mbit/s. Data are transmitted on one single burst on the uplink frame with a constant size of about 92 OFDM symbols in mode 7 (54 Mbit/s), 184 OFDM symbols in mode 5 (27 Mbit/s) and 278 OFDM symbols in mode 3 (18 Mbit/s). If elastic transmission was considered, the size of the transmitted bursts would be highly variable, some frames being almost full, other frames almost empty leading to a much more variable and degraded performance. Indeed, transmitting very long bursts leads to BER degradation since the channel response cannot be efficiently refreshed using only the 4 pilots included in data symbols. Results are depicted on the figures 7 and 8.

It is worth noting the relationship that exists between the BER and the PER. Indeed, in the case of HiperLAN/2, the PDUs (protocol data units) have a fixed length of 54 bytes (432 bits). In the "worst case", if errors were equally spread (AWGN channel, infinite interleaving), the ratio between BER and PER would be around PER/BER = 432. Of course, correlation occurs, especially on frequency selective channels. We can notice from our measurements that on average the ratio PER/BER = 20~30. In any cases, we can conclude that errors are grouped in packets and therefore mechanisms like ARQ or in a lesser extend Reed Salomon FEC in the layer 2 shall be useful and efficient.

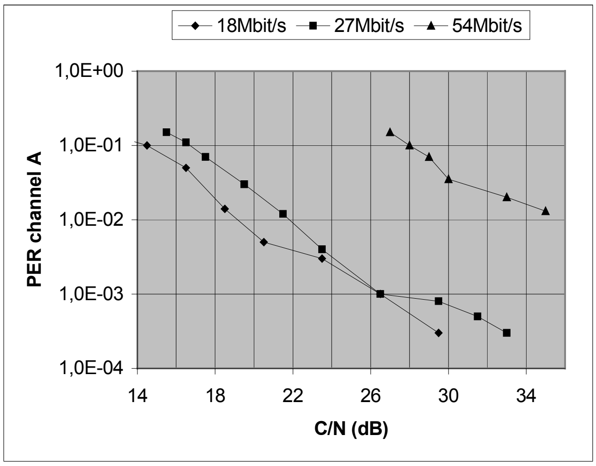

Figure 7: PER on pseudo-BRAN A channel.

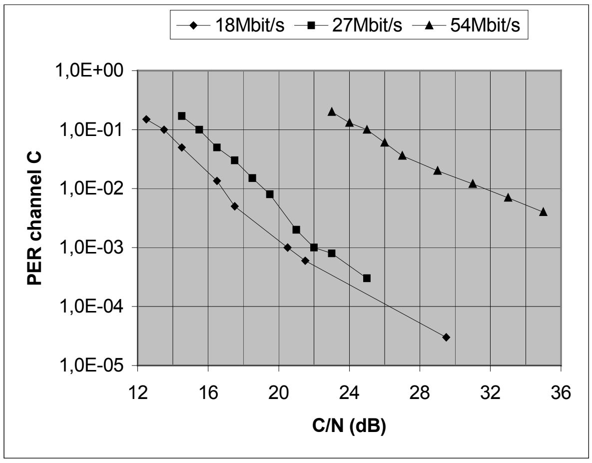

Figure 8: PER on pseudo-BRAN C channel.

4. PERFORMANCE WITH RADIO TRANSMISSION AT 5 GHZ

4.1. Performance issues

This section deals with the characterization of the HiperLAN/2 system when operating at 5 GHz in realistic situations. Three different results are presented in the sequel. (i) An evaluation of the achievable coverage between an AP and a MT for a 54 Mbit/s transmission. (ii) An evaluation of the performance for each PHY mode in a typical indoor environment. (iii) Comments on the advantage of centralized systems with respect to global synchronization performance for bursty transmission at 5 GHz.

It is important to note that for this section, the BER performance cannot be easily compared to theoretical results since the radio channel is not perfectly known. RF impairments like phase noise of local oscillators are also not precisely known and cannot be easily simulated. We identified three main scenarios to perform these tests: Outdoor line of sight (LOS), Indoor LOS and indoor non line of sight (NLOS). No ARQ is used for these tests in order to characterize the intrinsic performance of the physical layer. The effective output power of our system is +15dBm and the antennas are directive with a 100 degrees beam and a 4dBi gain.

Outdoor LOS condition: As mentioned above, the purpose is to transmit the maximum bit rate (up to 54 Mbit/s) with the minimum of errors (BER less than 10^{-6}) across a reasonable distance (tens of meters). Due to power supply limitation, we were only able to test a distance of 50 m in outdoor LOS condition (car park of a corporate building), with error free condition in all modes. It is likely that the same performance could be achieved over a greater distance of at least 80 m.

Indoor LOS condition: Typically, a BER < 10^{-8} was achieved in indoor LOS condition (or through a thin plastered/wooden wall) for all modes up to 10 meters.

Indoor NLOS condition: For indoor NLOS condition, we tested a scenario where the AP was located in a room and the MT was located in another room, with a distance between them of 25 m (figure 9). In that case, we observed a BER =10^{-3}~10^{-6} for 54 Mbit/s mode and BER <10^{-8} for lower modes (36~6 Mbit/s).

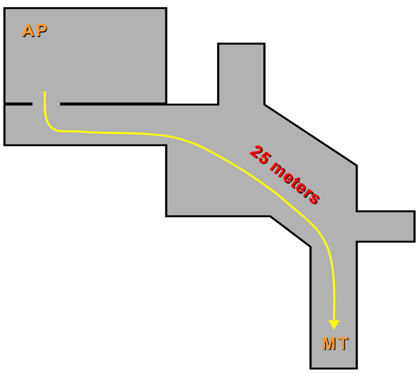

Figure 9: Indoor NLOS measurements.

The table 3 summarizes the performance evaluated in these three propagation environments. Thanks to the monitoring of the channel estimation statistics, we observed that real 5 GHz channels (indoor and outdoor) are usually less frequency-selective than the channels models of section 3. As a consequence the BER performance was mostly limited by the available C/N.

	Propagation condition	distance	Bit rate (Mbit/s)	BER
Outdoor	LOS	50 m	6 – 54	< 10^{-8}
Indoor	LOS	10 m	6 – 54	< 10^{-8}
Indoor	NLOS	25 m	6 – 36 54	< 10^{-7} 10^{-3} 10^{-6}

Table 3: 5 GHz radio measurement summary.

From a practical point of view, it is fair to say that the highest mode (54 Mbit/s) can only be used in good LOS condition (or through a thin plastered/wooden wall) up to a range of several tens of meters. Other modes will cover a various range of NLOS situations. In order to achieve very low BER and PER, mechanisms like ARQ (for delay-supporting applications) or Reed Solomon FEC (for real-time applications) in the layer 2 shall be used to compensate for bursts of errors.

4.2. Synchronization issues

The centralized resource allocation in HiperLAN/2 (contrary to IEEE802.11a) enables each receiver to know in advance when and from which terminal new bursts will arrive. Therefore, it enables to accurately average and track the synchronization parameters on a frame by frame basis. In other words, acquisition is performed at the beginning of the connection and afterwards the terminal focuses on tracking small deviations. This ensures a high stability and quality of the received signal. This requirement is particularly important when transmitting at 54 Mbit/s (64-QAM), this mode being very sensitive to impairments. Practically, an EVM (Error-Vector Magnitude) of at least 25 dB shall be achieved for the 54 Mbit/s mode to obtain a sufficiently low BER. To illustrate the kind of results obtained with the prototype, the figure 10 depicts the constellation diagram observed after equalization for a 64-QAM signal transmitted at 5 GHz on a LOS flat channel with a burst duration of 300 OFDM symbols. More generally, measures show that the prototype is able to properly synchronize even in severely degraded (high Doppler frequency) and noisy conditions. In particular, the synchronization robustness was tested using the channel emulator with 3 paths on the downlink and three paths on the uplink for pseudo versions of the BRAN channels. With a Doppler frequency up to 500 Hz (equivalent to a vehicle speed of 100 km/h at 5 GHz), the prototype was able to keep its synchronization thus allowing the demodulation of the received bursts. Naturally, the quality of the signal was sometimes highly degraded, but mechanisms like ARQ would allow to recover the lost packets.

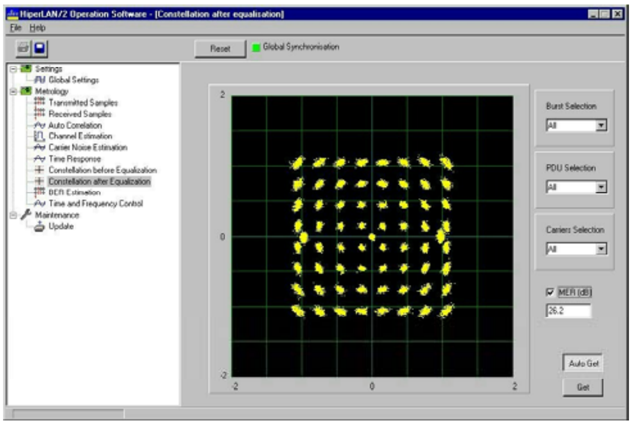

Figure10: Signal after equalization.

5. CONCLUSION AND FUTURE WORK

With a maximum of 54 Mbit/s available on top of the radio link, HiperLAN/2 systems are able to provide up to 42 Mbit/s at the application level with support of Quality of Service (thanks to a powerful MAC/DLC structure). However, this maximum capacity will only be available in good LOS condition up to a range of several tens of meters. Other modes (from 36 Mbit/s down to 6 Mbit/s) will cover a various range of NLOS situations (even industrial), which makes it very flexible. The combination of high throughputs and QoS support makes this technology very attractive. According to the results presented in this document, we can predict that HiperLAN/2 systems are perfectly suitable for the wireless transmission of broadband multimedia contents in a business, public or home environment. Future work will include the analysis of this system in severe environments (industrial) and the investigation of advanced link adaptation procedures.

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