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# A 802.11p prototype implementation

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***Abstract*** **- This paper presents an IEEE 802.11p full-stack prototype implementation to data exchange among vehicles and between vehicles and the roadway infrastructures. The prototype architecture is based on FPGAs for Intermediate Frequency (IF) and base band purposes, using 802.11a based transceivers for RF interfaces. Power amplifiers were also addressed, by using commercial and in-house solutions. This implementation aims to provide technical solutions for Intelligent Transportation Systems (ITS) field, namely for tolling and traffic management related services, in order to promote safety, mobility and driving comfort through the dynamic and real-time cooperation among vehicles and/or between vehicles and infrastructures. The performance of the proposed scheme is tested under realistic urban and suburban driving conditions. Preliminary results are promising, since they comply with most of the 802.11p standard requirements.**

## I. INTRODUCTION

The Wireless Access in Vehicular Environment (WAVE) [1] refers to a set of emerging standards for mobile wireless radio communications. WAVE or Dedicated Short Range Communications (DSRC) 5.9GHz as is also known in the USA, is part of the Federal Highway Authority's Vehicle Infrastructure Integration (VII) initiative supporting Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications for emerging Intelligent Transportation Systems (ITS). WAVE systems will be used due to low latency and high data rate requirements in a high mobility environment. The WAVE standard is being developed by IEEE to respond at the necessity to solve a common problem of many worldwide cities, vehicular traffic and related e-safety. In Europe the European Commission has also allocated the 5.9GHz band for priority road safety applications and inter-vehicle and infrastructure communications. The intention is to ensure the compatibility with IEEE standards even if the band is not exactly the same, but frequencies will lie close enough apart to enable the use of the same RF components.

The equipment for building the Road Side Unit (RSU) and the On Board Unit (OBU) prototypes (Fig. 1) is composed by the following set of devices: Field-Programmable Gate Array (FPGA) [2], Transceiver [3], Power Amplifiers - one of-the-shelf [4] and another developed by the authors for the 5.9GHz band - and appropriate antennas. The Altera Stratix II FPGA development kit is fitted with two analog-to-digital converters and two digital-to-analog converters which enable the generation and the acquisition of IF signals, respectively, which are up/down converted to the 5.9GHz band by the transceiver. The transceiver has a PA attached for the uplink. For the downlink, the antenna is directly connected to the transceiver.

Fig. 1. Developed prototype (OBU and RSU) [5].

To describe the work in more detail, this paper is structured as follows: in Section II, the system architecture and each layer implementation overview is provided, in Section III reference scenarios and applications are presented, while in Section IV measurements results are summarized. Finally, conclusions and future work are drawn in Section V.

## II. ARCHITECTURE

Our approach follows the WAVE layer model, with particular focus on developing an adaptive connectivity to an open service infrastructure that adds value to the RSU standardisation effort by creating the conditions for systems from different vendors to plug on a dynamic basis. Thus, the upper layers approach follows the OSI Model/WAVE Model (
Fig. 2) based on IEEE 1609.1 standard [6], and proposes a normalised communication with client applications or Resource Management Application (RMA) according to the standard, considering an adaptive service framework (Fig. 3).

The network layer follows the IEEE 1609.3 standard [7] and provides services to WAVE devices and systems. These services include management and data services within WAVE devices.

The lower layers support a single-channel system with the IEEE 1609.4 standard [8] medium access control (MAC) and physical layers. All these layers will be described further on this paper [5].

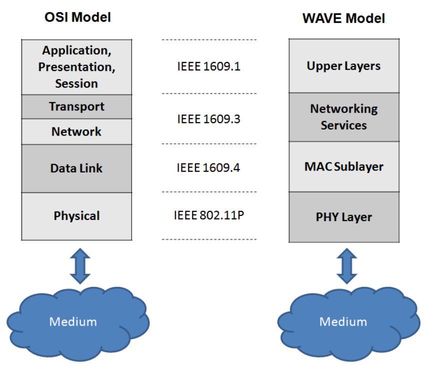



Fig. 2. OSI/WAVE protocol stacks mapping.

### A. Application layer

The main responsibility of the application layer is to manage resources interacting with a Resource Command Processor (RCP) on the OBU side. Considering the peer-to-peer communication model among OBUs, an OBU might also implement a resource manager to interact with other OBUs.

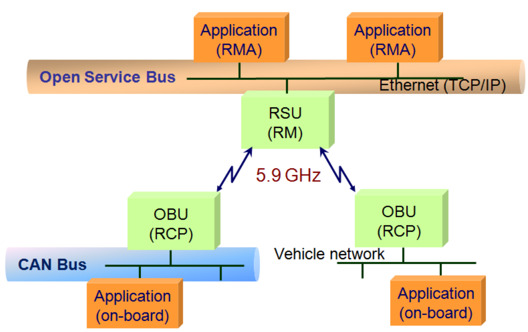



Fig. 3. The main parts of a DSRC 5.9GHz WAVE infrastructure [5].

While in this version the RMA is in the same computer, the proposal is to establish a cooperation model based on an open bus as proposed by Fig. 3.

In the hard-braking application, the OBU is in permanent contact with the vehicle Controller Area Network (CAN) bus using the On-Board Vehicle Diagnostics (OBD-II) interface, which is usually used for vehicle maintenance, diagnostics, repair and performance tuning. With this link, for example, it is possible to determine the acceleration of the vehicle and detect when a driver steps hard on the brake pedal, because a significant deceleration is detected by the OBU software [5]. Since the OBD latency may not be appropriate for real-time applications, an accelerometer could be an alternative solution.

### B. Network layer

The Network Layer is based on the IEEE 1609.3 [7] and it defines the network and transportation services, including the addressing and data routing required for data transference among WAVE entities. This layer can be divided into two major blocks: the management plane and the data plane. The Network Layer is responsible for managing connections between the Application Layers and the MAC layer as follows [5].

1) *The management plane* is achieved via the implementation of a specific management protocol, the Wave Management Entity. This protocol is responsible for the advertisement of the services being provided by the WAVE devices, for the base configuration of data connections, as well as for the maintenance of a local Management Information Base, containing the configuration and status information of the local WAVE device.

2) *The data plane* is divided in two separate sub-blocks: the Internet Protocol (IP) and the Wave Short Message Protocol (WSMP).

- The IP protocol is in fact an implementation of the IPv6 protocol, as it is currently known and widely implemented in other wireless communications. This sub-block is not implemented in this prototype version.
- The WSMP protocol has a key role in the WAVE technology, since it is responsible for managing the flow of short messages in a network of devices by exchanging data/information with very low latency.

### C. MAC layer

The MAC layer is responsible for controlling the medium access, giving higher priority to frames considered safety-relevant, through the use of Enhanced Distributed Channel Access mechanism, and shall operate in a multi-channel scheme, supporting a Control Channel (CCH) and multiple Service Channels (SCHs). The CCH shall be used to transmit WSMP messages, e.g. the hard-braking, and announce services, e.g. toll application. In the prototype, the MAC is essentially implemented by software, running in the FPGA embedded processor. It includes a component responsible for bridging the MAC to Physical layer (PHY) which is implemented in hardware. Since currently MAC is implemented in the FPGA, the communication with the Network layer is performed via a serial port (to be removed later), while communication with PHY layer is straightforward, because this last one shares the same FPGA.

#### 1) Transmission

When the MAC detects that a frame has been received from the Network layer, it examines the frame header in order to determine the frame type to be transmitted. The proper MAC fields are appended and a clear channel assessment process is performed. If the correct channel is tuned and if it is possible to transmit the information, the bit sequence is passed to the PHY layer. Otherwise, the frame is kept buffered for future retry.

### 2) *Reception*

When a bit sequence is received from the PHY layer, two levels of filtering are performed. First, address matching is done in hardware in order to avoid time consuming reads from buffers by the processor. After that, detection of errors is done by analyzing the frame check sequence. If the two operations are successful, the frame is buffered. The MAC fields are then processed and the appropriate frames are forwarded to the Network layer via the serial port.

## *D. PHY layer*

The PHY Layer is described according to two different functions: the transmission and the reception of bit sequences. When a transmission is being performed, the PHY receives bits from the MAC layer, processes them and transmits to the transceiver the appropriate physical signals to be up-converted. On the other hand, the reception chain will initially analyse the incoming signal, process it, extract the corresponding bits and send that bit sequence to the MAC layer. Thus, this layer can be seen as a three parts abstraction composed by:

- Physical Blocks;
- An intermediate frequency sub-layer;
- "Medium – PHY" communication.

### 1) *Physical Blocks*

The transmission chain is responsible for the operations scrambling, encoding and interleaving of the bits received from the upper layer (MAC).

The scrambling operation is performed to randomize the data, which minimizes the data "DC" bias and maximum run lengths, thus implementing a code whitening operation. One should note that the receiver will only be able to synchronize if the transmitter avoids the existence of sequences of too many consecutive zeros or ones. After this scrambling operation, the encoding is performed by a convolutional encoder to ensure a Forward Error Correction mechanism.

Finally, the bit sequence is "interleaved" which means that its bits are reordered according to a specified rule. The interleaver is defined by a two-step permutation. The first permutation ensures that adjacent coded bits are mapped onto nonadjacent subcarriers and the second will ensure that adjacent coded bits are mapped alternately onto less and more significant bits of the constellation and, thereby, long runs of low reliability bits are avoided.

The reception chain shall do the reverse operations of the ones made by the transmission chain. Following the 802.11p standard recommendation, the decoding is performed by an implementation of the Viterbi algorithm. The block used in our system is based on an IP core supported by Altera.

### 2) *Intermediate frequency sub-layer*

The IF sub-layer is responsible for physical signals modulation and demodulation are directly done in a lower frequency sub-carrier (4MHz). Frequency shifting from IF to/from RF is carried out by the transceiver.

One must stress that this sub-layer is not currently performing OFDM since this module is still under development. For test purposes, the IF sub-layer is performing a BPSK modulation at 1Mbps.

In the transmission chain, a bit sequence is received from the interleaver (previously described) and a simple NRZI coding is applied to this received signal. This coded sequence modulates a digitally generated carrier of 4MHz at 1Mbps using BPSK. Phase transitions occur when the carrier goes through zero. In-phase (I) and quadrature (Q) signals are generated in such way they provide lower sideband cancellation when up-converted to 5.9GHz.

The receiving chain is far more complex. The IF sub-layer receives I/Q signals from the transceiver, then an image-rejection mechanism (similar to the one present in the transmission chain) is applied to retrieve only the upper side-lobe. After this, band-pass filtering at 4MHz is applied. Synchronous demodulation is made at this point, for which a carrier extraction process is performed over the incoming signal. First the incoming signal is squared, then an 8MHz narrow band-pass filtering is applied, a frequency division by 2 is done in order to get a 4MHz signal and finally a small delay is applied to get a 4MHz extracted carrier synchronous with the incoming signal. An integrate-and-dump filter, a clock recovery unit and an NRZI decoder finally retrieve the baseband signal.

### 3) *Medium-PHY communication*

To make transmission possible through the medium, the transceiver needs to be locked in a specific frequency, which is selected depending on the desirable and selected channel.

After the transceiver is locked, an Automatic Gain Control (AGC) process starts at the receiver.

## *E. OFDM blocks*

Orthogonal Frequency Division Multiplexing (OFDM) is one of the requirements defined in the 802.11p standard for data transmission. This multiplexing technique allows data exchange with high data rates and robustness to errors.

As mentioned above, in the current version of our system, a single modulation is being used: the BPSK modulation with 1 Mbps of data rate. However, when using OFDM, it will be possible to transmit higher data rates (Table I).

TABLE I
MODULATION AND DATA RATES OF OFDM

| Modulation | Data rate (Mb/s) |
|---|---|
| BPSK | 9 |
| QPSK | 18 |
| 16-QAM | 36 |
| 64-QAM | 54 |

The standard specifies also some timing parameters that must be accomplished when implementing the system. Some relevant parameters are presented in Table II although many more parameters are specified by the standard.

TABLE II
TIMING PARAMETERS

| Parameter | Value |
|---|---|
| Number of data subcarriers | 48 |
| Number of pilot subcarriers | 4 |
| Number of subcarriers, total | 52 |
| Subcarrier frequency spacing | 0.15625 MHz |

Once again, the design and synthesis of the blocks described here were aided by Altera's software named *Quartus-II*. The schematic form was used to assure the communication between blocks.

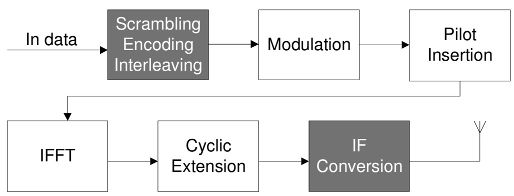



Fig. 4. The OFDM Transmission Operations/Blocks: Modulation, Pilot Insertion, IFFT and Cyclic Extension.

Fig. 4, illustrates the main operations performed to implement OFDM in the transmission chain: *modulation*, *pilot insertion*, *inverse fast Fourier transform (IFFT)* and *cyclic extension*.

In this context, the operation "Modulation" represents the mapping between the input sequence and Gray-coded constellations. Regarding the desired type of modulation, different conversions shall be performed. For example, if the desired modulation is 16-QAM, each group of four bits is divided in two pairs of bits, so the first pair defines the I value of the constellation and the last pair determines the Q value.

This process consists of a block that will generate modulation signals I/Q that depend on the chosen modulation. There is also a normalization step in order to achieve the same average power for all mappings, but it was not represented in the figure because it can be seen as a sub-block of the "modulation" one. On the other hand, Pilot Insertion introduces the pilot subcarriers in positions -21, -7, 7 and 21 into the OFDM symbol (composed of 64 values). These pilot signals are added in order to make coherent detection robust against frequency offsets and phase noise. The pilots shall be BPSK modulated by a pseudo-binary sequence to prevent the generation of spectral lines.

Another important block is the one represented as Inverse Fast Fourier Transform (IFFT). It is based on an Altera's IP-Core and it transforms data from the frequency domain to the time domain representation.

Finally, and in order to have a guard interval to avoid interferences between symbols, one should describe the Cyclic Prefix, which is basically to place in beginning of a given OFDM frame a copy of the end. To complete the transmission chain the signals are converted to IF band and then transmitted to the air.

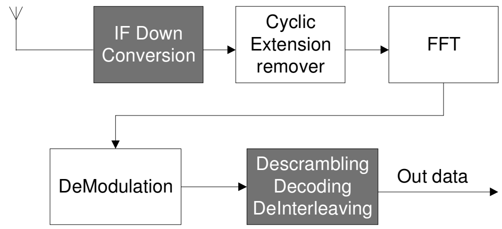



Fig. 5. The OFDM Reception Operations/Blocks: Cyclic Extension Removal, FFT and DeModulation.

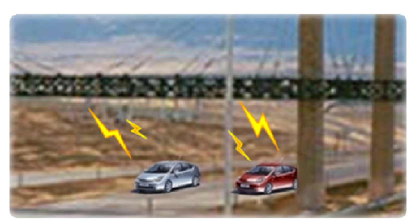
In the reception chain, Fig. 5, when information is received it is down-converted to base band where the cyclic extension is removed and delivered to the Fast Fourier Transform (FFT) block to transform the information from time domain to frequency domain. Then, a process is initiated that reverts all of the processes described in the transmission chain to recover the transmitted information and deliver it to the "Descrambling, Decoding and DeInterleaving" block, as can be seen in Fig. 5.

## III. SCENARIOS

As already mentioned, this work is based on three possible scenarios: hard-brake (Fig. 6a) and accident (Fig. 6b) for broadcast based services and tolling (Fig. 6c) for point-to-point based services.

a) Hard-brake scenario.


b) Accident scenario.



c) Tolling scenario.

Fig. 6. Services scenarios

In the hard-brake or accident scenarios, two OBUs are installed in two different vehicles. When a driver steps hard on the brake pedal or a crash occurs, an 802.11p frame is transmitted. For the tolling scenario, an OBU is installed inside a vehicle and a RSU is located in the motorway road side. The RSU periodically transmits a beacon signal. When an OBU receives the beacon it responds to the RSU indicating that the signal was received.


Fig. 7. Urban scenario used for tests.

In Fig. 7 can be considered the environment of the urban test site, where some buildings add some extra problems in communication, i.e., multipath interference.


Fig. 8. Bird's eye view of the roads used for test.

In Fig. 8 one can observe pieces of the motorway (the two tracks in the bottom) and the road (upper track) used for testing. These are open roads at constant height (near sea level) with some vegetation. The biggest trees between the two motorway tracks are about 3.5 m high.

## IV. RESULTS

After the development of the prototype, several tests were performed in laboratory in order to check the correct functioning of the system (Fig. 9). Then, the system was validated through outdoor environment tests. To accomplish these goals an RSU was placed near the road and the OBU was placed inside of a car.

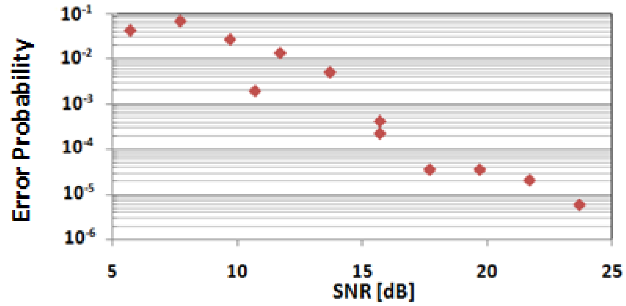



Fig. 9. Estimate of BER versus SNR in laboratory environment.

After this, some parameters were measured to evaluate the system and help to find the best place for the antenna location (Fig. 10 and Fig. 11).

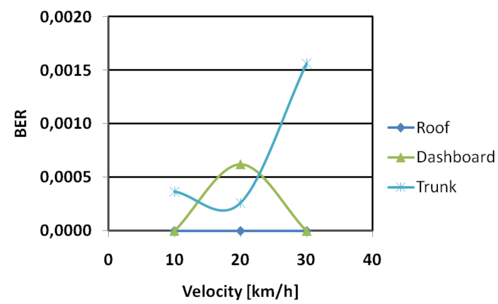



Fig. 10. Study of the antenna location relatively to BER.

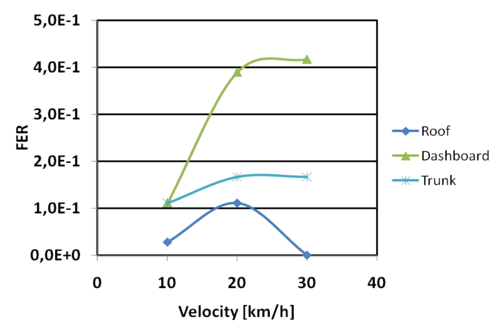



Fig. 11. Study of the antenna location relatively to FER.

Fig. 10 (roof location) shows that all bits were received correctly but in Fig. 11 it is possible to see that for the same location the Frame Error Rate (FER) it's not zero. This is due to the fact that some frames are lost in the communication, so it does not enter to the Bit Error Rate (BER) calculation, but even with some frames lost, the roof is by far the best place to put the antenna. Other tests were made with RSSI (Received Signal Strength Indicator) and the input power. They both confirmed that the roof was the best place to put the antenna.

These two parameters show the number of wrong bits or frames for different speeds. Such measures were done at a maximum speed of 30 km/h in the urban scenario (Fig. 7), and the distance achieved was about 400m where the communication was lost.

Despite not measured the BER and FER at higher speeds, communication was tested positively between a vehicle moving at 100 km/h and a stopped vehicle beside the road, when separated by nearly 1000 meters. The same distance was achieved between two cars moving in opposite directions, with a relative speed above 240 km/h.

## V. Conclusions

With line of sight, communication was possible with low FER/BER at approximately 400m with 22 dBm EIRP. However, even at shorter distances, communication is affected by obstacles such as trees or buildings. This effect can be overcome, of course, with higher transmitted power.
In the other scenario tested (tolling) the results were very satisfactory because we tested it in open road condition. Line-of-sight was usually available, but sometimes it was lost due to vegetation and other vehicles. Communication is possible at higher distances, approximately 1000m with the same EIRP of 22 dBm.

It is expected that OFDM chain blocks, in the near future, will enable improved FER and BER performance because these Tx and Rx chains are capable to prepare and handle errors introduced by the radio channel.

The messages transmitted and received across WAVE protocol do not actually implement security aspects as defined in IEEE1609.2. To improve the security of our services, future work will embrace these features in our implementation.

Relatively to MAC layer, its implementation is currently based only in IEEE 802.11 [9]. Future work should embrace the functionalities described in the IEEE 1609.4 standard (channel coordination is already under implementation).

## Acknowledgements

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