A Possible MAC Layer Implementation for Dedicated Short Range Communications

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Abstract — **DSRC (Dedicated Short Range Communications) is a well known widespread technology. One of the main applications of DSRC is RTTT (Road Transport and Traffic Telematics), especially EFC (Electronic Fee Collection) on tolled roads, bridges or tunnels. Other vehicle-related applications had been envisaged, such as car parking or fuel refilling automatic payment. These applications were successfully developed, deployed and are in current use in Portugal. Especially for EFC, medium access control is of utmost importance. In this paper we present a possible implementation scheme for the MAC-layer, suitable for low-cost microcontrollers, to operate between the two equipments (as in fig.1), the RSE (Road Side Equipment) and the OBE (On Board Equipment). The result is interface software that controls the referred communication, embracing hardware and software into a join solution.**

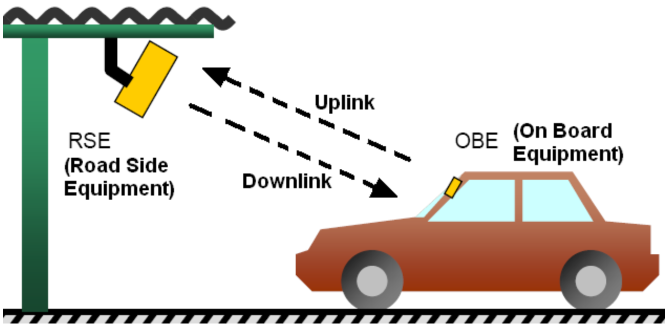

Fig. 1 – The practical application of the communication equipments.

I. INTRODUCTION

European standards were developed by CEN (TC278) regarding the normalization of DSRC systems for RTTT. These standards include EN 12253 (physical layer) [1], EN 12795 (MAC/LLC layer) [2], EN 12834 (application layer), EN 13372 (communications profiles) [3] and EN ISO/ETSI 14906 (interface for EFC – electronic fee collection).

EN 12795 specifies all the Medium Access Control (MAC) and Logical Link Control (LLC) parameters for both the OBE (On-Board Equipment), the identifying tag usually placed at the windshield and the RSE (Road Side Equipment), placed at the toll. Communication from the RSE to the OBE is named Downlink, while communication from the OBE to the RSE is named Uplink. This project provides a solution, according to the features and constrains of the standard and this is explained with more details in the following sections.

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II. COMMUNICATION ISSUES

A. Frames

The Communication between OBE and RSE, both Uplink and Downlink, is based on frames exchange.

The frames have the format shown in Fig. 2 and are described in the following paragraphs. There is also a special case of frame, without the LPDU (Link layer Protocol Data Unit) field, used in some specific situations. The size of the whole frame varies from 9 bytes up to 138 bytes, and this variation is associated with the LPDU field.

The frame is delimited at the beginning and at the end by a single byte with the value is 01111110 (base 2).

The Link Address Field has 5 bytes and contains the LID (Link Identifier), which is used to keep the communication private between different users.

Flag	Link Address Field	MAC Control Field	LPDU	Frame Check Sequence	Flag

Fig. 2 – Frame Format

The MAC field is a single byte (please see fig.3) and it is used to: indicate if the frame contains an LPDU, specify the transmission direction, allocate public/private windows and also request private windows.

L	D(b)	A or R	C/R	S	X	X	X

Fig. 3 – MAC Control Field format

- L: indicates the existence or absence of the LPDU on the frame. If L equals ‘1’, LPDU exists, otherwise it does not.
- D(b): indicates the link direction, if b equals ‘0’ is a downlink and if equals ‘1’ is an uplink
- A: indicates window allocation (only used in downlinks);

R: indicates window request (only used in uplinks)
- C/R: identifies the LPDU as a command or a response. If C/R equals ‘0’ LPDU is a command otherwise is a response
- S: distinguishes the first allocation of a private uplink. (for downlinks it is considered a don´t care)
- X: Don´t care

The LPDU has from 10 up to 128 bytes and carries information regarding the OBE User and one byte for control.

The Frame Check Sequence field has two bytes and is used for error detection.

B. Address establishment

The fixed equipment (the RSE) supports an SAP (Service Access Point) to broadcast and other SAPs to communicate privately with the mobile equipments (or OBEs) within the communication range. Each OBE also needs to have at least two SAPs to establish the communication, (please see Fig 4).

It is assumed that the Broadcast SAP is always active (actually it is in sleeping mode most of the time). The OBE responds by creating a private LID and requests a Private SAP. When a frame containing a private LID is received by the RSE, it is created a new corresponding SAP.

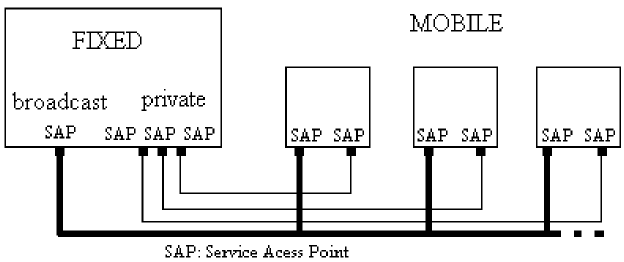

Fig. 4 - Address Establishment

C. Window management

Basically there are three different situations of message exchange each one with a specific time displacement, where the OBE must be aware of and behave according to it.

The first situation happens when the fixed equipment broadcasts a message in a Public Downlink Window and expects the response(s) in the following three consecutive Public Uplink Windows (please refer to Fig. 5). T3 (160µs) is the downlink to uplink turn around time, T4b (32µs) is the maximum time to start of transmission and T5 (448µs) is the time duration of the uplink window

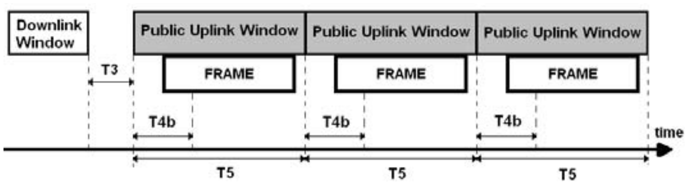

Fig. 5 – Exchanged Windows after a Public Downlink

The second situation happens when the fixed equipment transmits in a Private Downlink Window (please see Fig. 6) and the corresponding response arrives in a Private Uplink Window. T3 (160µs) is the downlink to uplink turn around time, T4a (320µs) is the maximum time to start of transmission.

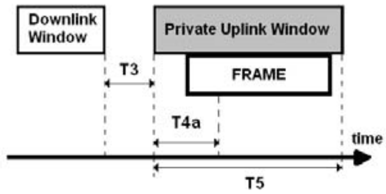

Fig. 6 - Exchanged Windows after a Private Downlink

Public and private Downlink/Uplink windows are distinguished by their LID, whether a Broadcast LID or a Private LID is present.

Besides these situations, there is a third, the minimum time gap between an uplink followed by a downlink (T1). This corresponds to 32µs.

D. Example of frame exchange

Fig. 7 describes an example of the ideal exchange of frames between the fixed and the mobile equipment and also the communication primitives within the LLC. The meaning of the acronyms included in the figure will become apparent later.

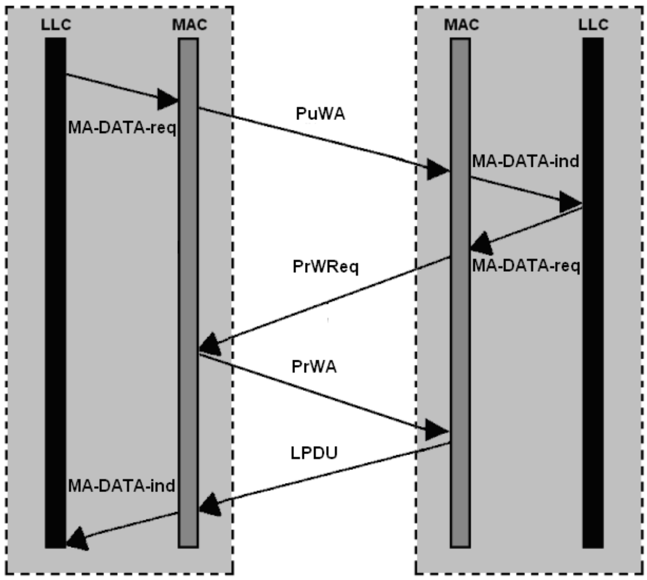

Fig. 7 - Communication example between OBE and RSE

E. State Machine

The following state machine, see Fig 8, describes the behavior of the OBE, when is within the RSE range.

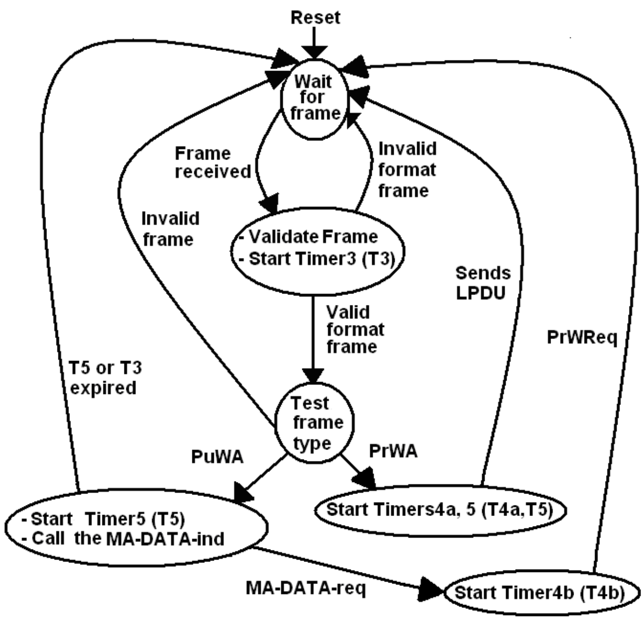

Fig. 8- State Machine describing the MAC layer behavior of the OBE

The following paragraphs explain the process, state by state, and the corresponding transition conditions are indicated. The discussion is separated from Public to the Private Allocation, beginning in the point where the state machine finishes the common steps.

- 'Wait for frame' State:

In this state, the OBE is waiting for a new input proceeding from the RSE, whether it is the first or any other frame, during the communication.

  - Transition condition: the reception of a new frame.

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- 'Validate Frame/ Start Timer3 (T3)' State:

In this state, the frame is validated by comparison with the pre-defined format, particularly the Cyclic Redundancy Check (CRC). Timer3 (T3) is enabled. This timer is used to control both situations (Public or a Private Uplink Window)

  - Transition conditions: If an error occurs during the validation, the process returns to 'Wait for frame'. If not, it advances to the following state.

- 'Test frame type' state:

Here the distinction is made between a PuWA (Public Window Allocation) and PrWA (Private Window Allocation)

  - Transition conditions: If the frame received is a PuWA, advances to 'Start Timer5 (T5)/ Call the MA-DATA-ind' state. If it is a PrWA, advances to 'Start Timers4a, 5 (T4a, T5)'.

Public Window Allocation branch (please see Fig.9)

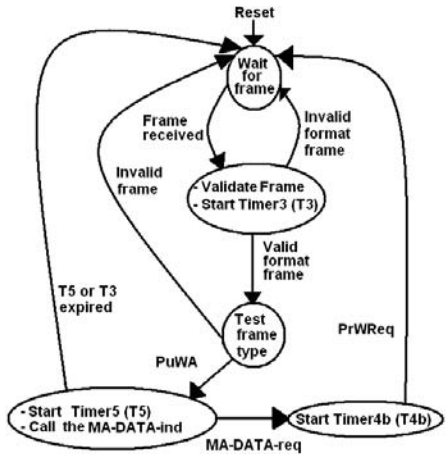

Fig. 9 – State machine concerning only the Public Uplink branch

- 'Start Timer5 (T5)/ Call the MA-DATA-ind' state:

The Timer 5 (T5) is enabled. This timer controls the time duration of the uplink window. Function MA-DATA-ind is called. This is the pre-defined MAC service primitive to communicate into the LLC layer.

  - Transition conditions: If T3 or T5 expires, the process will end and return to the initial state 'Wait for frame'. If the response is a request, through MA-DATA_req, the state will change to the 'Start Timer4b (T4b) state'.

- 'Start Timer4b (T4b) state'

This is a quite simple state, it just starts the Timer4b (T4b), to control the correct time to send the information. PrWReq is sent and the process returns to the 'Wait for frame' State.

  - Transition condition: PrWReq is sent

Private Window Allocation branch (please see Fig 10)

If in the 'Test frame type' state a PrWA is detected, the following state will be 'Start Timers4a, 5 (T4a, T5)'.

- 'Start Timers4a, 5 (T4a, T5) state:

Both Timer4a (T4a) and Timer5 (T5) are enabled, to proceed with information sent.

  - Transition condition: The pending LPDU is sent.

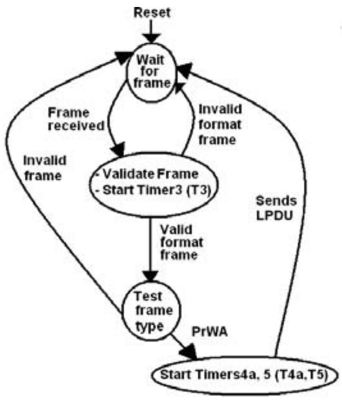

Fig. 10- State machine concerning only the Private Uplink branch

F. Software

The software is being developed in C language. Some software functions regarding the OBE are already developed.

Software to simulate the RSE behavior in the interaction with the OBE was also developed. There was also the need to develop some functions of the next layer (the application layer), to test some conditions in the MAC layer.

The service primitives to communicate with the next layer LLC are: MA-DATA-req(LID,LPDU) and MA-DATA-ind(LID, LPDU), shown in figure 11,, they are still being developed**.**

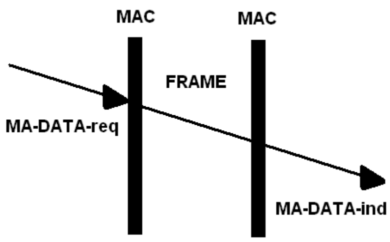

Fig .11- Service Primitives of the MAC layer

G. Test Conditions

The test conditions are in accordance with the European Standard EN 12795. The conditions are tested one at a time. The software is tested first in well known conditions with specific values being inserted step by step. After the simulation, it is tested with real conditions.

There are, so far, a few practical problems that are being tested such as synchronization between the send and delivery of frames in the OBE/RSE connection.

III. EXISTING WORK

This works is part of a larger project which aims the construction of two compliant units: an OBE [4] and a RSE [5]. The hardware for both devices is in advanced development state, with two laboratorial prototype units built as can be observed in the pictures. Also, a first bare software layer is written and tested, covering physical frame transmission and reception, as well as some MAC details as bit stuffing/de-stuffing and Cyclic Redundancy Check (CRC) generation and checking. This software was developed for Atmel's AVR family of microcontrollers, which are present on both devices and where the MAC/LLC software also runs.

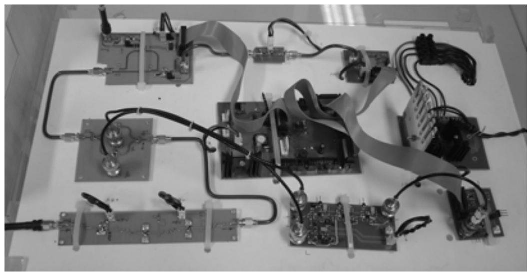

Fig. 12 - Existing RSE hardware

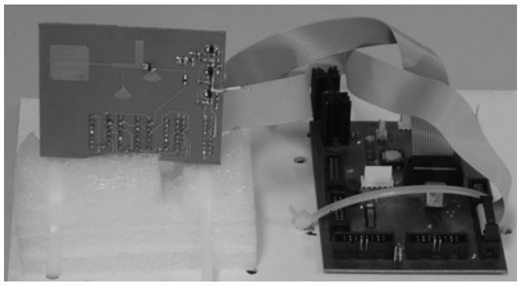

Fig. 13 - Existing OBE hardware

IV. CONCLUSIONS AND FUTURE WORK

The presented state machine complies with the demanded features and constraints required by EN 12795. Moreover, it is robust to communication errors and/or unexpected messages. However, this approach is still simple enough to be implemented in a low-cost microcontroller with typical features. This is an ongoing work which will culminate with robust service primitives for the MAC layer.

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