

# The Virtual Token-Passing Ethernet Implementation and Experimental Results

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## Abstract

*This paper presents the design and first experimental results of VTPE (Virtual Token-passing Ethernet). VTPE is a deterministic protocol for real-time applications based on shared Ethernet, aimed to be used either in small processing power processors or in powerful ones. It is based on implicit token rotation similar to the virtual token-passing used in the P-NET protocol. The VTPE implementation leads to reduced program code, thus fitting in small microcontrollers' memory and imposing low communication overhead.*

## 1. Introduction

Ethernet is currently the most widely used local area network (LAN) technology in the world. However, it cannot provide a real-time service to the supported applications as the underlying CSMA/CD access protocol does not provide a deterministic arbitration mechanism. Therefore, it cannot guarantee that data delivery deadlines will be met. In fact, such non-deterministic arbitration mechanism poses serious challenges concerning the real-time support of data communications.

Several approaches and techniques have been developed to provide a real-time behaviour to Ethernet-supported applications, taking advantage of the low cost associated to this technology and also of the available data-rates that are much larger than those of most real-time fieldbuses available today. Some of these approaches are based on the modification of the Medium Access Control [1], the addition of transmission control [2], a protocol using time-triggered traffic [3], or the use of switched Ethernet approaches [4].

The objective of this work is to find Ethernet deterministic solutions, so that it becomes possible to use it to interconnect sensors, controllers and actuators at the field level. Such solutions are based on the Virtual Token-Passing Ethernet-VTPE protocol, proposed in a previous paper [5]. The major objective of this paper is to present and discuss the implementation of the VTPE protocol, as well as the preliminary results obtained.

This paper is organized as follows: Section 2 briefly presents the VTPE protocol. Section 3 presents the available implementation of VTPE. Section 4 presents some results obtained in the implementation and Section 5 presents future work and concludes the paper.

## 2. VTPE presentation

The VTPE protocol [5] implements an implicit token rotation procedure (similar to the virtual token-passing used in the P-NET fieldbus protocol [6]) upon the Ethernet MAC layer, guaranteeing the deterministic medium access. In order to preserve the compatibility with existing hardware, the virtual token-passing scheme is implemented using the standard Ethernet's broadcast destination address, guaranteeing that all the devices are able to read each frame dispatched on the bus.

In a VTPE system each producer node is identified by a node address number (NA) between 1 and the number of producers expected within a system and has an Access Counter (AC) that identifies which node can access the bus in a specific time interval. Whenever a frame is sent to the bus, an interrupt will be generated in all producer nodes. After such interrupt, all the producer nodes will increase their AC counters. The node whose AC value is equal to its own unique address is allowed to access the bus. If the actual node doesn't have anything to transmit (or indeed it is not present) the bus becomes idle and, after a certain time, all the access counters are automatically increased by one (which corresponds to an implicit token passing). The next producer is then allowed to access the bus. If, again, it has nothing to transmit, the bus continues idle and the described procedure is repeated until a producer effectively uses the bus. When the access counter exceeds the maximum number of producers, it is reset to 1 and the implicit token-passing cycle is repeated again.

To implement the virtual token passing all producers must have a *timer*, which can be programmed with time value  $t_1$  or  $t_2$ .  $t_1$  must be long enough to enable the slowest processor in the system to decode the VTPE frame (read the frame).  $t_2$  is used to guarantee the token passing when one or more producers don't have something to transmit.

After the end of a frame transmission all the producers will re-initialise their *timers* with the  $t_1$  value. After  $t_1$  expires each producer node sets its *timer* with the  $t_2$  value, increases its AC and checks if it is equal to its own node address. Two possibilities can occur:

- The node whose AC is equal to NA will immediately start a frame transmission if it has something to transmit and then it sets the timer with the  $t_2$  value.
- The nodes with NA different from the current AC value will set their timers with the  $t_2$  value.

After the expiration of  $t_2$ , each producer will check the Bus Status register of the Ethernet controller to verify if there is a frame being transmitted. If true, all the producers will wait for the interrupt that will occur at the

end of the frame and increase the value of their access counters.

To prevent inactivity in the bus during a long time interval, which could lead to a significant clock drift among system nodes, a timeout is considered too. After the timeout expiration, the node that has the right to access the bus must send a special message.

### 2.1 The VTPE original format frame

The VTPE protocol uses the MAC Ethernet frame, encapsulating a special frame (VTPE frame) inside the Ethernet data field. This is shown in fig. 1.

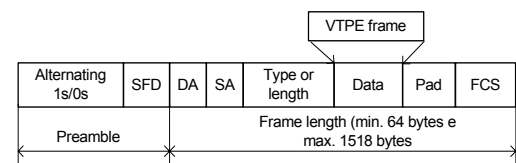


Fig. 1 Virtual Token-Passing Ethernet MAC frame

The VTPE uses the type field instead of the length. It represents a reserved constant value, which must be used by all the VTPE messages on the network. The use of this field allows supporting the coexistence, in the same network, of other protocols. Upon a frame reception, each node will check the type field and will only perform further processing if the frame is relevant. Nevertheless, all the nodes producing non-VTPE frames need to implement the VTPE access control, as frames cannot be allowed to access the bus outside the authorized time intervals, that is, whenever the AC is not equal to the producer NA.

The VTPE frame carries one control field and one or more messages as it is depicted in the figure 2.

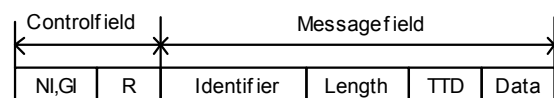


Fig. 2 - VTPE frame format

Since VTPE can send more than one message inside a single Ethernet frame, more efficient bandwidth utilization is achieved due to the reduction on padding in the case of small messages. Like it is shown in figure 2, the VTPE frame is composed of two parts: the control field and the message field.

### Control field

The control field is two bytes long, being the first byte divided in two parts. The four less significant bits (NI) identify the number of messages inside the Ethernet frame (up to 16 messages). The remaining four bits are the Group Identifier (GI), which will be used to create different producer groups, *i.e.*, sub-networks. The GI idea permits to reduce processing overhead in the nodes by isolating devices that do not belong to the same group. In fact, upon the frame reception, the nodes will check the GI field and only perform further processing if the frame is relevant. The second byte of the control field (R) is reserved for future use.

### Message field

The message field is composed by the identifier, the data length, the TTD (Time to Deadline) and the Data itself. The identifier must be unique and identifies the VTPE message in the system. It is 2 bytes long and thus can address 65536 different message streams. The TTD field is two bytes long and is reserved to indicate the time remaining to the message's deadline. The Length field is two bytes long and indicates the number of bytes in the VTPE message. The VTPE data field is variable, so it can be as small as one byte or as long as 1492 bytes. It must be remarked that the Length field is two-byte long and theoretically it could indicate a 65536 bytes long frame. However, the maximum number of data bytes that are allowed per frame in a VTPE message is 1493 bytes (1500 bytes for the maximum number of data bytes inside a single Ethernet frame minus 7 bytes for the control field and the VTPE message's header).

To minimize the overhead on small processing power devices, messages from and to these nodes must be compatible with their processing capacity. However in this implementation was considered packet size varying from the minimum Ethernet packet value (60 bytes) to the maximum value supported by the used hardware. The maximum VTPE packet length will be fixed further.

## 3. VTPE implementation

### 3.1 The hardware

The block diagram of a VTPE node is shown in figure 3. A VTPE node consists of an eight-bit microcontroller PIC 18F458 [7] attached to a Packet Whacker Ethernet board [8] based on the RTL8019AS [9] Ethernet controller.

At initialisation, the RTL8019AS uses the EEDO, EEDI and EESK lines to find an extern EEPROM and gets the MAC address. As the hardware does not use an extern EEPROM, the PIC, besides simulating the EEPROM presence, also supplies the MAC address. This

approach simplifies the hardware and makes easier the modification of the MAC address value.

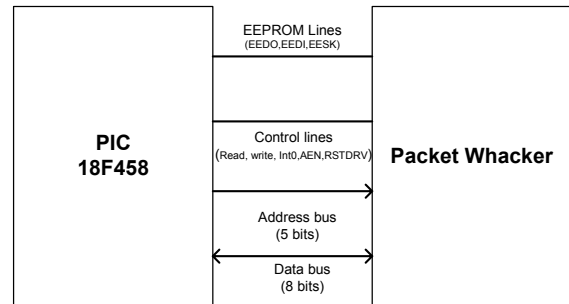


Fig. 3 VTPE node block diagram

The developed VTPE system consists of three nodes interconnected by a hub/switch device.

### 3.2 The software

Currently the VTPE software is still being developed. It is written in C using the PICC18 compiler and developed recurring to the HI-TIDE environment.

Basically the code consists of:

- A function to initialize the Ethernet controller;
- Two functions, one to write data into the Ethernet controller and other to read data from the Ethernet controller, and;
- A function to run the VTPE protocol, *i.e.*, to increase the access counters and to decide if the node has the right to use the bus.

## 4. Experimental results

The tests carried on until now are aimed to show the system working in the virtual token-passing bus arbitration fashion and to determine the least  $t_l$  value to run the VTPE, as well as, determine the bandwidth utilization. For this particular test it was defined that:

- Each node must transmit a predefined VTPE frame per time as depicted in figure 2;
- The Ethernet frame carries data varying from the smaller frame (46 bytes of data) to 1242 bytes;
- The measured  $t_l$  is the least value to run VTPE using all processor computations resources.

A timer to counter the  $t_l$  value is started whenever the Ethernet controller generates an interrupt, *i.e.*, when it accepts a good packet. This timer is stopped after the incoming packet is decoded and checks if the node has the

right to use the bus. This value is exactly the least  $t_1$  value to run the VTPE protocol in the above considerations.

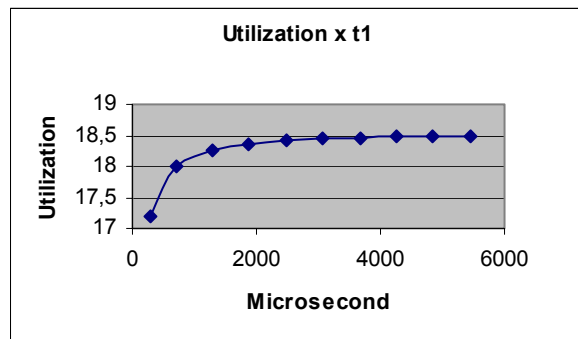
The  $t_1$  measured and the calculated bandwidth utilization is shown in figure 4.

Data(Bytes)	t1(uS)	Utilization(%)
46	297,6	17,2
138	693,6	18
276	1288,8	18,25
414	1883,2	18,35
552	2476,8	18,41
690	3071,2	18,44
828	3665,6	18,46
966	4260	18,48
1104	4854,4	18,49
1242	5448	18,5

**Fig.4 Measured  $t_1$  and calculated bandwidth utilization**

The limit of 1242 bytes of data is due the internal RAM memory available in the used microcontroller. No external memory is available in the hardware.

A graphic showing the  $t_1$  versus the calculated bandwidth utilization is shown in figure 5.



**Fig.5 Bandwidth utilization versus  $t_1$**

## 5. Conclusion and future work

This paper presents the current development state of a demonstration for the VTPE protocol.

The VTPE code for this implementation is very small. It occupies approximately 9% of the available flash memory of the microcontroller used. This is an important result because this VTPE version is to be used in small processing power processors.

Reasonable bandwidth utilization (18,5% with minimum packet size) was obtained. This is can be considered a good resulted since a small processing power microcontroller is used.

The utilization doesn't increase a lot with the Ethernet frame length due to the interface between microcontroller and Ethernet controller is 8 bits length;

To continue the development of VTPE some improvement will be done, for example:

- To implement a mechanism to facilitate the system management;
- To develop and validate mechanisms to promote fault tolerance in real conditions of operation, namely a solution based on the publication of the individual access counter values.
- To continue the VTPE development a new implementation will be made in FPGA.

## References

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