Hybrid Time Triggered Protocol for Home Wireless Communications

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Abstract—**During the last few years an increasing focus has been made by the research community in utilizing wireless sensor networks (WSNs) in an abundant variety of different applications. Such types of sensor networks are usually supplied by non-rechargeable batteries in order to reduce the expenses. Multi-hop wireless sensor networks frequently utilize a time-division multiple-access (TDMA) plan with the purpose to systematically gather data from various positions of an extended region. The proposed access methods for the Medium Access Control (MAC) in this study combine hybrid proprieties. The proposed MAC specifies that in a given time interval the access to the medium has to be entirely free and without restrictions between the exterior nodes. While this event lasts, the nodes compete for a slot in the network. The proposed methodology corresponds to time-division hybrid multiple-access (TDHMA).**

Keywords—MAC; TDMA; Wireless sensor networks; Microcontroller unit; Wireless protocols.

I. INTRODUCTION

Circa 3% of the global energy consumption is credited to the Information and Communication Technology (ICT), and the resulting CO_2 emission from the aforementioned consumption is approximately 2%. Such a share of CO_2 emissions matches the ones of airplanes and 25% of passenger vehicles emissions. Besides, due to the reason that energy cost shows an increasing tendency, and the necessity for broadband expansion to as many areas as possible, the research made in energy efficient WSNs is considered to be a central investigation direction in the ICT industry [1]. In order to better comprehend this target, such type of research has become an auspicious solution for the aim of reaching sustainable and economical operations of ICTs [2].

The constant progress verified in the field of electronics and microcontroller units (MCUs) has compelled WSNs as an answer to many different applications such as traffic monitoring, video surveillance, tracking systems and object detection, etc. Usually, such types of networks are comprised of a vast amount of distributed nodes that autonomously reorganize into a multi-hop wireless network. Every one of the nodes is comprised of one sensor, one battery, an embedded processors and a low-power radio [3].

In numerous WSNs propagation delay displays a random nature and the transmitter is unable to correctly forecast the distance from the receiver, resulting into an flawed synchronization between both transmitter and receiver [4][5].

In this paper, the presentation of the distributed wireless communication platform is made. The implementation of Medium Access Control (MAC) is described, the structure of the software is analysed in detail and then the experimental tests and the obtained results are discussed.

The aforementioned platform is centralised in one coordinating node designated for each base station – BE. It plays an important role in the management of the network resources: temporal synchronisation of the infrastructure elements, traffic configuration and the allocation of the channel phased by time. The other elements are known as client stations – CS. They are passive nodes that depend on the management directives of the BE node. The direct exchange of data between two CS stations is not authorized – the packets are always directed to the coordinating station.

The proposed access methods for the Medium Access Control (MAC) in this study combine hybrid proprieties. That is, it displays several imported characteristics from two protocol families, with and without restraint. A classical approach is proposed enhanced with advanced aspects that grant certain sophistication to the developed experimental system. First, in general terms, the access is defined by a temporal control of utilisation time meaning that there is not a dispute or competition for the medium in the case of transmission of data. This concept is explored in a way in which the CS station could transmit in a deterministic manner without interference or delays committed by other CS stations. The ownership of time is not exchangeable. This method is best known as time-division multiple-access (TDMA) [6]. Second, the software that operates the distributed communication admits the entrance in real time of candidate nodes as network clients. This implies that the scheduling times of channel utilisation – time slot – is initially a dynamic process. The time slot segments which are not reserved for a free CS yet are taken to the competition in a competitive dispute between two CS contender nodes to the network.

The proposed MAC specifies that in a given time interval the access to the medium has to be entirely free and without restrictions between the exterior nodes. Consequently, the data traffic follows the TDMA method while the allocation of the time slot proprieties is more similar to access medium – Carrier sense multiple access (CSMA). This particularity gives to the TDMA a certain transfiguration. While this event lasts the nodes compete for a slot in the network. The proposed methodology has been designated as time-division hybrid multiple-access (TDHMA).

The applications for the BE and for the CS stations were created with the aid of the EZ430-RF2500 tool combined with a CC2500 radio and with a MCU of the MSP430 family – MSP430F2274. Combined with this development tools is a debugger that possesses an USB interface for a PC communication. The connection is intended to programming of the MCU, to data collection and to debugging task execution.

II. TDHMA WIRELESS COMMUNICATION PROTOCOL

A. General features

The communication platform is centralized in one coordinating node designated by Central Station – EB. It carries an active role in the management of network resources: temporal synchronization of infrastructure elements, traffic configuration and time-phased channel allocation.

The remaining elements are known as Client Stations – EC – passive nodes that depend on the management directives of the EB node. The direct exchange of data between two EC is not possible. The packets are always sent to the EB. The MAC access method proposed in this paper combines several hybrid properties thus granting a certain intricacy to the developed experimental system.

First, the distributed communication protocol admits the entry in real time of nodes that are contenders to network clients. This implies that the scheduling of time slots is initially a dynamic process. The free time slot segments (that are not reserved to any EC node) are the prize in a competition between the contender nodes to network clients. First, in generic terms, the access is made through a vision of temporal control of the utilization time meaning that there isn't any competition to the medium for data transmission. This concept is explored so that the EC could transmit in a deterministic form, without interference or delays committed by other ECs – the possession of time is not interchangeable.

The data traffic follows the TDMA formula while the allocation of the time slot propriety is in line with the CSMA method. This particularity grants to the TDMA a certain transfiguration. Thus, to the methodology is given the name of TDHMA - time-division hybrid multiple-access. This arbitrariness premise aims the competition between stations that intend to be admitted in the network.

The process of competition aims the dynamic configuration of new elements, being enough the prior attribution of an identification number to every contender node (variable station ID). The remaining information from which could result an acceptance (association) or a rejection is of EB's responsibility. The interaction between ECs and EB is made with a collision detection algorithm and packet rescheduling.

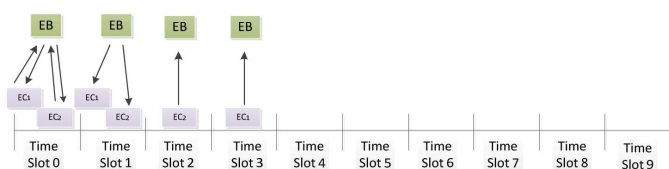Fig. 1 shows the TDHMA access model.

Fig. 1.   Temporal diagram – TDHMA frame.

The RF channel is organized in 10 slots with 100ms duration each. The structure or frame displays the total amplitude of 1ms. The renovation of the frame is continuous with periodicity of 1s.

The first time slot (TS0) adopts the CSMA method – the nodes make their requests of network association to the network by listening to the channel and detecting if there is any transmission in progress. When the admission is finalized, the node acquires the propriety reserve over its attributed time slot for undetermined time. The next time slot (TS1) is responsible for the transmission of service codes by the EB entity to the network elements (the communication is unidirectional). As for the next segments – TS2-TS9 – they are reserved to client entities with an affiliation to the network.

B. EB Synchronisation of the EC nodes with the EB node

The temporal alignment of EC nodes is achieved with a synchronism packet broadcast by the EB thus representing the starting coordinate of the frame. After the reception an EC node activates an internal clock whit a limited duration of one second. The clock is used by the EC to schedule the MCU actuation mode under the arrangements with the network.

If the client station is still not an integral part of the network the synchronism signal will trigger the admission protocol in the time slot TS0. The procedure will take place until the end of the time slot if the entry attempts fail during time counting. When the deadline expires without a positive answer the station awaits for the next synchronization channel. By receiving the available time slot number the node changes to the listening mode in time slot TS1 and performs the data transmission in the next slot according to the indications given by the EB node.

If the node is already an integral part of the time slot TS0 then is ignored with the arrival of the synchronism signal. The MCU standardly listens in time slot TS1 thus behaving as programmed for the transmission slot reserved for this purpose. If the EB node is silenced all the ECs connected to the network will indefinitely remain in a moment of waiting by the synchronism signal.

C. Association of the EC node to the network

The EC predates the initialization protocol by listening to the channel. By means of an internal function of the CC2500 radio the application makes the Clear Channel Assessment (CCA) signal reading. Since a null is devolved it awaits in a standstill until proceeds to a new listening period. If this attempt fails it awaits a few instants before attempting a new reading. The alternation undergoes until the extinction of time slot TS0. However, if gap appears in the channel without traffic an admission request is generated to the network coordinator with the Request Time Slot (RTS) frame.

Next, the EC station commutes the radio to the reception mode (RX) and remaining in this state while awaits the enquiry result to the EB node. After the awaiting time ends if the application in EC verifies that there is not any feedback from the EB node then it returns to the previous step. If the opposite is verified (the RTS packet is seized) the EB node returns it with the availability code frame (CD) addressed to the contending station. If the availability code is 99 this means that there isn't any slot available. If the code is comprised between 2 and 9 the client station deciphers how the time slot number is assigned.

As this phase is reached the time slot stays with a pending reserve. That means that the right of the reserve has already an owner. However, it will only be unblocked for transmission effects.

After the CD frame is processed the EC node ends the association process with an Acknowledge frame (ACK) directed to the coordinating station. This frame is used to inform that the availability code was received. The frame is transmitted two times more. It expected that the redundancy of the process will safeguard the capture of information by the EB node. Similarly, to what occurs before, the delivery is conditioned to the listening signal CCA and followed by a waiting time for the situation of the channel in use as well as for after the first two transmissions. It remains to mention that the EB node only closes the association process with the capture of the ACK frame. Without this frame the coordinating node keeps the classification of association pending. The EC need could be following the transmission schedule. However, the data frames will not be processed while the reception of the ACK is not finished – they will be discarded. Only then the client station gains the status of an element of the network.

D. Packet types and services

1) Node synchronization

The data packet of the node synchronization can be seen in Fig. 2. The 0xCC code in the second byte of the data informs that the ECs have to restart their counting of the local time with a new TDHMA frame. The next byte has no meaning. I tis reserved for a future revision of the protocol. The RTS packet has the detailed constitution shown in Fig. 3.

The second position in the data frame characterizes the nature of the frame: the 0xAA code is perceived as a solicitation of an access to the network. In the next position follows the identification of the contender node. The remaining positions don not have any use in the present version.

2) Network Association

The CD packed is of EB station's responsibility. It has a simplified composition when compared to the RTS packet. Given that this is a communication directed from EB to an external node of the network a sender element of the frame was adopted as the identification number of the EC that requires the association. This packet comprises the result for the admission inquiry and can be observed in Fig. 4.
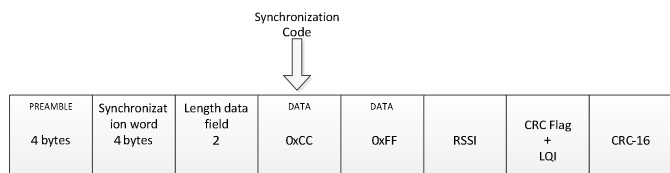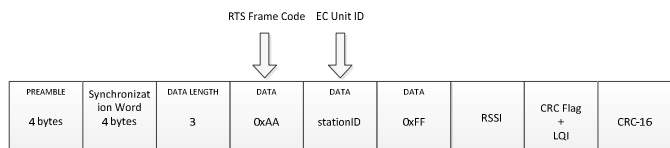
The ACK packet closes the association program whose structure can be seen in Fig. 5. The 0xBB code reports that the previous communication with the free time slot number was received by the contender station. The following byte clarifies the origin of the sender. The 0xBB code is not decipherable by the associated ECs thus they ignore this packet.

3) Service orders

This type of frame introduces flexibility in the relation between the coordinating station and ECs connected to the grid. It allows the coordinating station the configuration of the data traffic. This packet can be seen in Fig. 6.

In the present version, the configuration order is universal. It is broadcasted to all ECs. The 0xDD in the second byte identifies the frame's nature. The commander byte of the service (CS) is designed to transport up to 255 different instructions or service codes. At the moment only two service instructions are formalized:

a) The 0xF0 command: Sorts the transmission of sequential number.

b) The 0xF1 command: Sorts the transmission of temperature measurement (internal reading of the MCU core).

4) Data transmission

The direction is always from ECs to the EB. They are two modalities of data. In the first one the data field is filled with the identification number of the EC station plus the 0xF0 code corresponding to the current service order thus ending with the global numerical variable. This variable represents a number between 0 and 255, is incremented to the unit between consecutive transmissions.

All the EC stations in the first transmission act (after the association to the network ended) assume the variable as null. The same rule was considered in cases when the EC unit loses the synchronization signal or the synchronization is made by an internal software. The data packet: numerical sequence can be observed in Fig. 7.
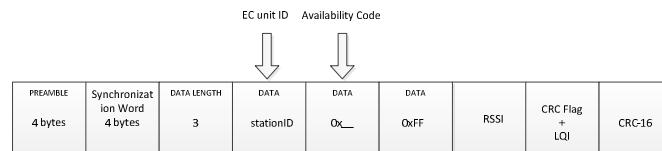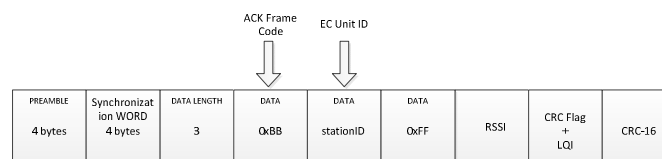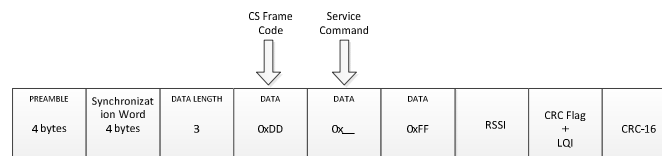

Fig. 4. CD packet.

Fig. 2. Synchronization packet.

Fig. 5. ACK packet.

Fig. 3. RTS packet

Fig. 6. CS packet.

In the second modality the number of useful data increases to four. The first two bytes of the data field (not counting the length byte) comprises the identification of the station and the service code 0xF1 respectively. The two following bytes transport the temperature result variable ADC.

A reading of the temperature sensor is obtained that accompanies the MCU's core. The value is sampled 10 times, without pauses between samples, thus being converted in an average value. The samples are generated with the reception of the CS packet and with the service code 0xF1. The second-to-last byte is reserved for the two most significant bits (the sampling of the temperature is translated in a representation with a resolution of 10 bits) while the last byte is destined to the 8 less significant bites.

The inclusion of the service code in the data frame could appear to be redundant. However, this could not be more further from the truth. The decision is justified by recalling an improbable and anomalous event. Due to the distance between EB unit and a given EC unit, the latter could be localized in site with some electromagnetic interference.

If, for instance, this happens during time slot TS1 and if the intensity is significant it is probable the CD packet with an actual command service for the TDHMA cycle will not arrive in manageable conditions for an effective demodulation. This means that the packet is discarded. In a more extreme example in which the new service directive will not coincide with the instruction of the TDHMA cycle then the EC unit, without having the knowledge of the actualization, will execute the previous memorized code. All other units commute for the required data flux.

When the frame associated to the dissenting EC arrives to the EB, this on, in turn will execute the comparison test between the sent code and command order in force at the time will then verify that there I no compatibility. The EB will rebuke the frame thus ignoring the remaining content. This event is signalled to the exterior with the message LOST (scheduled communication service not carried) in the information display that comprises the graphical interface that supports the distributed application. The test data packet: MCU internal temperature reading can be seen in Fig. 8.
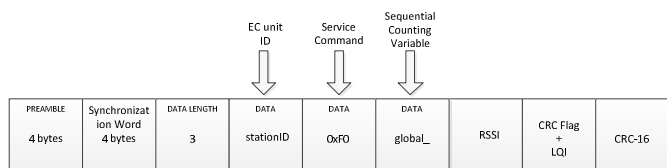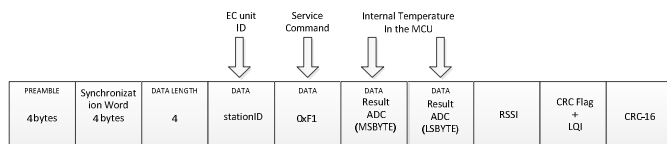

Fig. 7.   Test data packet: numerical sequence.

Fig. 8.   Test data packet: MCU internal temperature reading.

III.   IMPLEMENTATION AND TESTS

A.   Hardware

1)   MSP430F2274

The 2274 suffix appoints to a specific model of the line of MCU products MSP430. It has a RISC architecture of 16 bits. It operates with low supplying voltage between 1.8V and 3.6V. The basis of time of the clock is generated with an internal electronic oscillator configurable between 1 and 16 Mhz. The consumption is localized near 270 µA and 1 MHz in the active mode and 0.1 uA in Standby Mode or Off Mode. It comes equipped with 32kB flash memory and 1kB of RAM memory. It has an internal analogic converter of 10bits with a maximum of 200 000 samples per second and has an internal reference and a data transfer controller DMA. It comes provided with two 16bits timers and each one with three comparison and event capture registries. It also includes two universal series interfaces of communication, one dedicated to the synchronous connections and other one more comprehensive allowing the transmission and reception in an asynchronous mode.

2)   CC2500 based Wireless node

The hardware is the same for the EB as for ECs. The data lines between the MCU and the radio come predetermined by the layout of the EZ430-RF2500 kit (SPI bus and interruption signals). In the radio CC2550 the PLL internal circuit is supplied with a quartz oscillator of 26 MHz. In the MCU such external accessory does not exists meaning that the clock signal is formed with the digital internal oscillator DCO. The selected mediums in the embedded applications differ in one aspect for EB as for ECs: the analogic digital conversion module it is only utilized in the EC node. As for the remaining functions, the A0 timer is responsible for the generation of the periodic signal that allows to temporize the internal activities in the MCU unit and at the same time to tune the temporal basis of the EC node with the temporal reference of the EB node. The B0 timer serves to define standstill times during the application execution in the EB unit as well as in EC units. The final counting time in both timers is monitored by specific interruption routine services. The arrival of data to RX buffer is signalled with the passage of the logic level 0 to 1 in the 6th pin and port 2 through pin GDO0 (instructed for this same operation). The GDO0 pin is part of the set of specifications of the software in the experimental version with basis in extra time. Fig. 9 presents the electric connections between the MCU and the radio kit EZ430-RF2500.
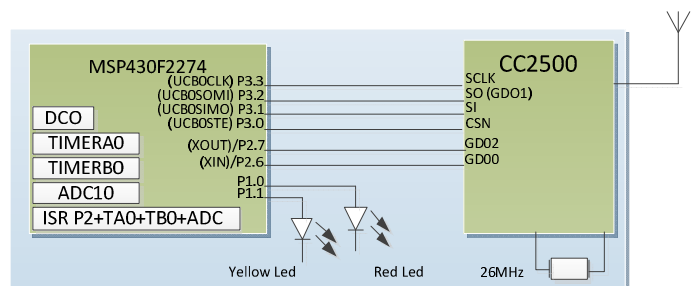

Fig. 9.   MSP430F2274-CC2500 electrical layout.

B. PC based graphic interface

For testing purpose the practical evaluation requires a means of visual interface in order to reinforce the results analyses. To this end, it was implemented a simplified visual interface based on Hyper Terminal. Despite being an outdated software it enables quick communication interface between the PC and a MCU for prototyping embedded systems. Although it is not the perfect candidate for a graphic platform, it was created an information board updated in real time allowing to follow the TDHMA MAC operated network activity.

The time slot states are update at pace of each TDHMA synchronization signals. Each time slot is identified with S followed by a number and the following four ASCII characters are used inform about the connection state and when applied to report the data been transmitted by the slave stations. Regarding time slot usage state two codes were implemented. The NCON expression means the time slot is not tied to a specific client node. In the event of a communication failure from a client node that has a programmed communication event, the time slot information window in Hyper Terminal is filled with LOST code. The first two time slot segments since are not reserved for real data transmission but only for supporting RF nodes dynamic allocation services. They are filled with NU expression meaning not used.

In addition each allocated time slot is tested from client station side by sending two set of data which are MCU internal temperature readings and a numerical sequence of numbers. These data sets are periodically an alternatively transmitted following the pace imposed by the TDHMA synchronization signal.

C. Experimental results

Even though the wireless communication system accepts up to 8 ECs, the validation tests were only performed with 2 kits EZ430. The TDHMA test design can be observed in Fig. 10. The certification of the system has to be restrained, at least at this stage, in numerical terms to the experimental universe of EC units.
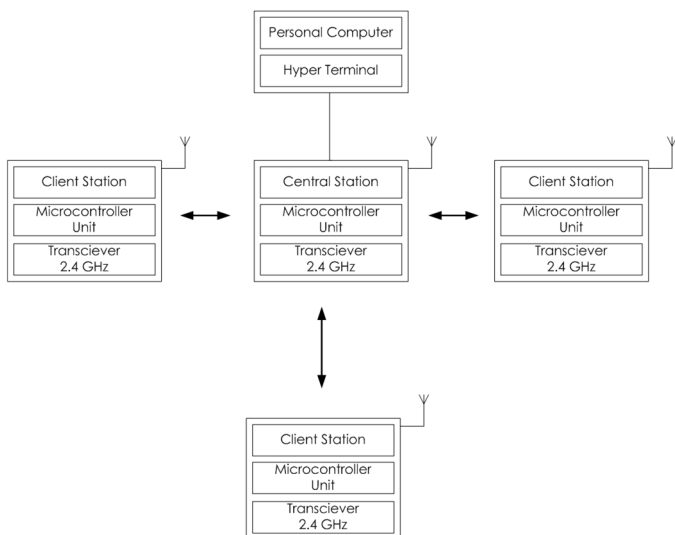

Fig. 10. TDHMA test diagram.

One of the platforms of one of the kits was named as EB station thus it received the network management software. The remaining three platforms were numbered from 1 to 3, respectively. It was made so through the marking of the identification number of the variable station ID that is the integrant part of the variable set in the main module in C.

First, it was tested the individual sequential association in a manual regime. For the first association, as for the next two associations, the protocolled time average did not exceed 3-4s thus being measured minimum admission times close to 1s. In this modality of tests the results can be classified as good, without revealing residual imperfections in the association or management algorithms. As such, in the first scrutiny a scenario was simulated with a gradual deactivation of all three ECs after the connecting the network. The software in EB proved to be robust by detecting the loss of connection in the set of all three nodes. The occurrences are reported in the HyperTerminal with the "LOST" message. By electrically rehabilitating the EC units the readmission time is remarkably low and is close to 2 s. In several situations the recovery was immediate.

Figs. 11-13 show the graphical interface in the setting of the related results.
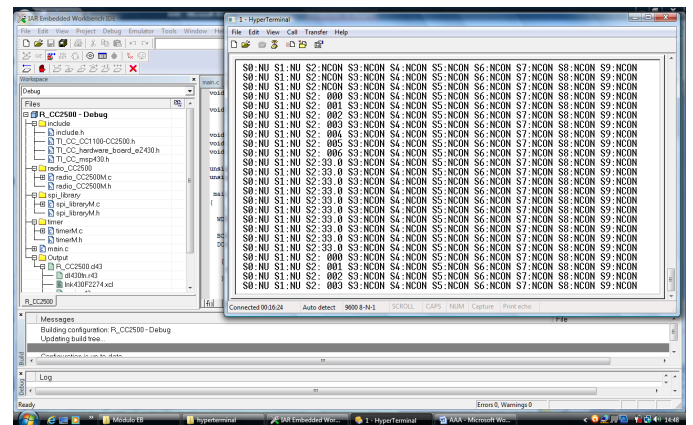

Fig. 11. Association of the node EC to time slot TS2: ongoing transmission of data.
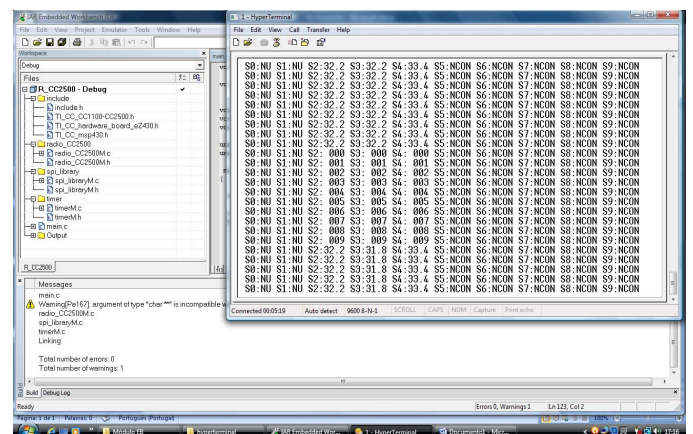

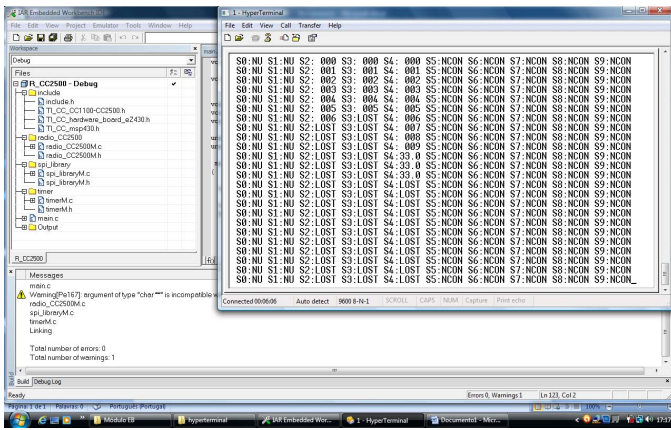Fig. 12. Time slot TS2, TS3 and TS4 reserved and with complete connection.

Fig. 13. Time slot TS2, TS3 and TS4: transmission compromises missing.

Later, the capacity of the system during initiation was analysed by effectuating the attribution of the time slot in a situation of full competition. Three EC contenders were connected to the battery and set in listening mode and waiting the synchronism frame. Only after that the execution order of the hosted code in EB platform was given. Through the means of this approach the behaviour of channel listening algorithm was analysed as the starting point of the admission protocol of the TDHMA frame.

Exhaustive tests were made in this regard. The three contenders ended up by obtaining the association without temporal or functional constraints. The effective connection was quick and significant delays were not observed between contender stations. In a few times a combined delay was found: none of the stations is able to be admitted before the 10s mark. However, this type of occurrence was a rare event and does not have any practical significance, thus no further attention was given to it.

IV. CONCLUSION

This paper has presented and verified a hybrid medium access control protocol for home wireless communication applications designated as TDHMA. The tests undertaken to validate TDHMA MAC based home wireless communication protocol were performed with two EZ430-RF2500 kits.

One RF unit was used as master station while the remaining three RF were given the role of slave stations. The test results cannot be seen as definitive because of the comparatively low number of slave nodes used. In other words, less than half of the TDHMA time slots were used. Therefore, it is recommended that the validation of the TDHMA protocol be limited to the number of RF units involved in the present evaluation. The testing of the protocol was conducted in three phases. First, it was evaluated without competition between RF nodes. This means the RF nodes were powered on sequentially after the previous node has been accepted in the network. In the next phase, the network was initiated with all RF nodes competing at the same time by the time slots. The implemented firmware has showed that the average time for associating all the three RF nodes to the network did not exceed 4 s. Therefore, the algorithm concerning dynamic allocation of the RF nodes to the free time slots has proved to work well. In the last phase a scenario with gradual power off the three nodes it was simulated after being associated to the network. The goal was to verify how quickly the slave stations are again incorporated in the network. In order to this, the slave station needs to use again the dynamic association mechanism that is part of the TDHMA protocol. In this context, the slave stations readmission have shown a reintegration time of 2s, while in some tests the network integration was immediate.

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