

MP-HA: Multicycles Protocol for Hospital Automation over Multicast

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Abstract— This paper presents a Multicycles Protocol for Hospital Automation (MP-HA) that works over multicast addressing and use a Master-Slave architecture. The protocol creates a segmented logical network based on multicast addressing associated with hospital beds. The objective of MP-HA is to ensure the determinism on network through medium access control mechanism increasing the transmission throughput. Thus, it creates a periodical environment making use of the parallel cycles which is called multicycles.

Index Terms— Automation, Hospital Automation, Multicast Network, Safety, Network Protocol, Ethernet.

I. INTRODUCTION

The development on the electronics field has contributed to a growing demand of distributed applications that provides the utilization devices with an embed power process [4]. For example, some industrial networks already use intelligent nodes for the processes control. For Pedreiras [9], this occurs because of the computing decentralization trends that now converge to distributed environment.

In this context, the hardware and software features have to be over all nodes and not only over one central processor. There are concepts on the industrial automation and some of them were foreseen on 1976 by Nitzan and Rosen [6], such as: data acquisition for processes control; signal monitoring and processing; cost reductions; processes optimization. These concepts have being applied in medical fields, in others words, they are also used on the hospital automation [2].

The hospital automation begins to request applications

that seek to improve the processes found in the hospital environment. Murakami [8], Várady [11] and Varshney [12] who propose patient's tracking systems.

There is a problem with automation systems that use Ethernet (IEEE 802.3) as its basic protocol [5]. Ethernet makes the automation of some processes that need reliability and that impose temporary restrictions unfeasible. There are some technologies that support temporary restrictions, priority and reliability [10], such as: Profibus, WorldFIP, Foundation Fieldbus, Controller Area Network (CAN) and DeviceNet. These network technologies used in the industrial automation become a solution for hospital automation. However, the installation of this solution has high cost and low interoperability [3], turning them not so attractive. Thus, the Ethernet networks are proposed as a technology to be applied in the industrial automation, due to the advantages, such as: expressive interoperability, high acting and low cost [5].

In this context, the Ethernet for industrial automation needs protocols that can ensure determinism and reliability. In the literature, we can find some researches that aboard these issues TDMA (Time Division Multiple Access) [1], VTPE (Virtual Token-Passing Ethernet) [3], FTT-Ethernet [9] and H-BEB [7]. These approaches are efficient in guaranteeing the determinism in the net. However, they don't present scalability politics and they present problems regarding the optimization of channel allocation. Such aspects happen when:

- Idle slots are observed in the net (approaches based on TDMA and their variations);
- Existence of long cycles (approaches based on TDMA token pass);
- Rejection of new nodes in the net (approaches based on the node admissions control);
- Technology used is already in disuse (approaches based on CSMA-CD - Carrier Sense Multiple Access / Collision Detection).

This paper presents the Multicycles Protocols for Hospital Automation (MP-HA), which will be used in hospital environments ensuring network determinism and optimizing the transmission factor of use. The Figure 1 illustrates the model of hospital automation proposed in the MP-HA. Differently from the previous works based on Ethernet protocol for industrial automation, the MP-HA works with logical segmentation of network. The process of net logical division is transparent and based on address multicast. The MP-HA works on IP and Ethernet Switch with support the multicast in level 2.

The model of hospital automation proposed in MP-HA and the Illustration 1 is divided in the following way:

- A) Monitored patient;

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- B) Sensor of reading of the patient's state: for example glucose sensor;
- C) Acts in the patient starting from the data informed by the sensor: for example glucose infusion and;
- D) Device that allows monitoring the patients.

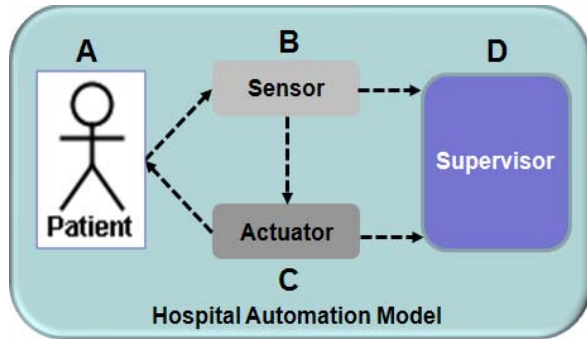


Fig. 1 - Model of Hospital Automation

II. OVERVIEW OF MP-HA

MP-HA is a protocol that uses the concept of messages groups segmentation, because it works with IP protocol, leaning on multicast addresses. Using multicast address MP-HA associates a hospital bed to a multicast group and a multicast group to several medical devices (network nodes).

This strategy allows MP-HA to define a transparent method of segmentation to the user (the supervisor's operator), and it also creates an associative link between the messages and the beds (patient). In this way, a node that sent a message to bed n , will only be received by other node of the same bed and the service provider MP-HA. The service provider is able to receive all of the messages. An important aspect of MP-HA in the use of the multicast address is the

increase use factor of the net, because this strategy promotes a mechanism that turns more efficient the messages distribution process. Thus, it avoids redundancy in the sending of data due to adopted strategy in MP-HA, joined to the multicast transmissions characteristics.

The Figure 2 exhibits the architecture of MP-HA, illustrating an overview of the context described in this section, where MP-HA divides a cycle in two windows of time: synchronous and asynchronous one. The windows of synchronous messages are used for transmission of control messages and data. The windows asynchronous messages are used for alarms and control messages. Observing bed 03 it is noticed that the data is sent only one time for all nodes of the group. These characteristics contribute to reduce the protocol communication cost.

The characteristic that motivates adoption of the Ethernet is that most of the hospital environment has the network based on it. The cost for installation will be reduced due to the use of the existent network infrastructure.

The MP-HA is based on a master-slave existent structure and in the multicycles concept. The master-slave structure is based on the token pass and dispute does not exist, creating a deterministic atmosphere in the network. Under multicycle concept, the MP-HA develops several independent and parallel cycles, that don't generate interference or competition with devices that are part of different cycles. Then, MP-HA allows optimizing the temporary cycles, because the cycles don't grow in function of the amount of nodes that are part of the net, but, in function of the amount of nodes enrolled in each group (hospital bed).

The logical segmentation based on multicast develops smaller cycles, allowing to send the messages faster in each group. The duration time of cycle is given by the sum of the time slot used for the transmissions of each message. The master controls the cycles generated in the group (bed), guaranteeing the synchronization of the net nodes and

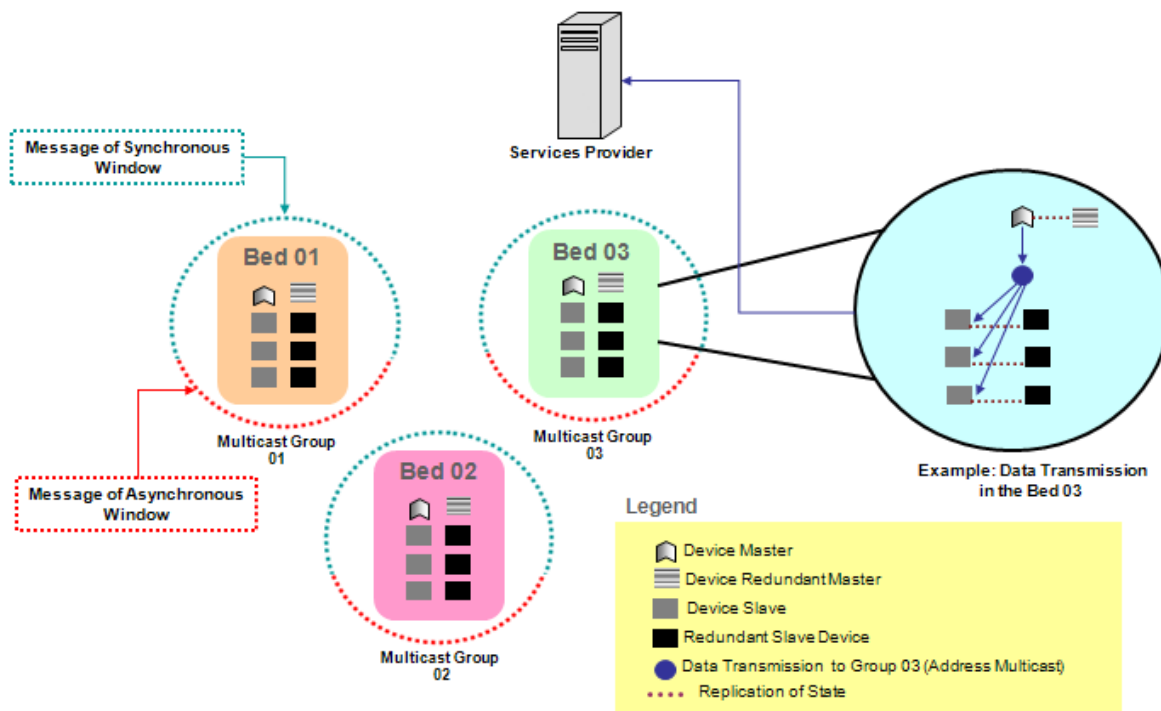


Fig. 2 - Overview of the MP-HA Architecture

consequently its respective periods for messages transmission.

III. ELEMENTS OF PM-AH

The PM-AH is composed basically of four elements: Services Provider (SP), Master, Cycles and Messages.

A. Services Provider (SP)

The SP provides essential services to the network (initialization, communication, verification and nodes re-indexing) and to the control over all messages in the network.

The SP saves the messages and supply data for the supervisory, allowing that hospital staff to monitor the patients. In PM-AH, the initiation and the formation of the multicast groups is accomplished through association tables. In Figure 3, it is possible to verify the structure of the storage table in PM-AH.

An important factor in the structuring of data is the addresses table (bed ► multicast) that associates a bed with a multicast group. From this table the SP informs the node in which multicast group should be enrolled before sending their messages of data.

The groups table (bed ► device) illustrated in the Figure 3 is dynamically created starting from the registration of the nodes in the networks. An aspect that can be verified in this table is the fields:

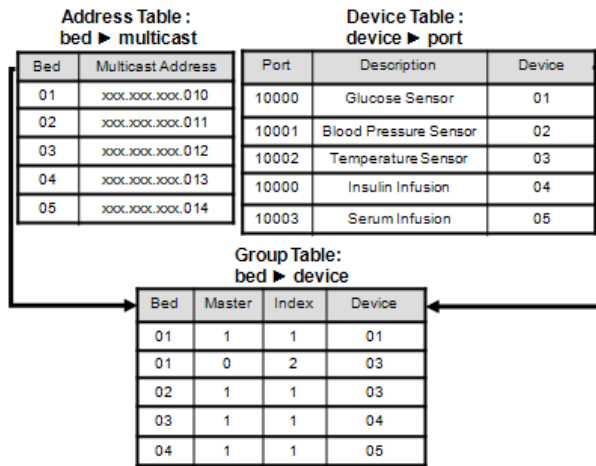


Fig. 3 - MP-HA: Tables of Support

- Master: it indicates if the node is or not the master of the group (1. Master, 0 - Slave);
- Index: it shows the sequence of nodes registration in the group (bed). This information allows the master control the token pass.

The devices table (device ► door) associates the device with a communication door to exchange data among similar devices of the same group.

B. Master

The group master in PM-AH is indicated by the SP. The master definition process starts when the node sends a request message of registration in multicast group (*rmrmg*). After the message was sent to SP, this one verifies whether there is a group master already. When there is no group

master, the SP sends a confirmation message of registration in group multicast and the node becomes the master one. The master node always receives the index one, so the next nodes will receive the previous index increased by one.

The master coordinates the cycles in its multicast group by token pass. Each node receives the token one time per cycle. The tokens are sent through a passage message of token (*tpm*) that indicates which device will have the ownership of the physical middle. So, the device will send a data message (*dm*) for its multicast group and SP.

The coordination of the net through the master using the multicycles concept and token pass contributes as follows:

- It avoids problems of package queuing in the switch;
- It ensures the determinism in the network, because the data flow is controlled;
- It increases the scalability of the net;
- It optimizes the cycle times, once that slot of idle time won't exist in the net.

C. Temporal cycle: Synchronous and Asynchronous Window

MP-HA is a protocol that works with cycles, a cycle in MP-HA is divided in synchronous and asynchronous windows. The cycle duration is defined by the time between synchronous windows. All nodes in a multicast group receive a starting message synchronous window (*smsw*), which indicates the beginning of the synchronous window.

The duration of the cycle is equal to the sum of the synchronous window and the asynchronous one. The Equation 1 shows how to compute the time of the synchronous window (T_{sw}):

$$T_{sw} = \left(\sum_{m=1}^q T_{p_m} * T_v \right), T_p = \left(\frac{d}{c * \beta} \right), T_v = \frac{L}{R} \quad (1)$$

Where,

q = Number of nodes in the group (considering the master node);

T_{mp} = Time of message propagation in the physical channel;

d = physical distance;

c = light speed;

β = range of channel transmission;

T_v = Time of message transmission according to range of network transmission (10Mb/100Mb/1Gb);

L = Message length;

R = Transmission Rate.

D. Request Message of Registration in Multicast Group (*rmrmg*)

The *rmrmg* is the first message sent by devices when they are initiate. This message is sent every second until the node that sent it, receives the first confirmation message of registration in multicast group. The format of the message is illustrated in Figure 4 and described in Table 1.

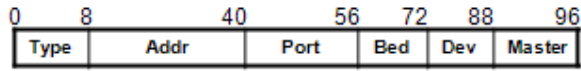


Fig. 4 - Format of rrmrg

Table 1 - Description of rrmrg

Field	Size	Description
Type	8 bits	Type of message that is being sent.
Addr	32 bits	Multicast address for registration in group.
Port	16 bits	Destiny Port.
Bed	16 bits	Number of the bed where the device is.
Device	16 bits	Type of device.
Master	8 bits	Identify if the node is able to be a group master.

E. Confirmation Message of Registration in Multicast Group (cmrmg)

The confirmation messages of registration in group multicast (cmrmg) are sent by the SP as an answer to the rrmrg. The cmrmg confirms in which group the device is enrolled, it informs the device index in the network and it indicates if the device is the master of the group. The format of the message is illustrated in Figure 5 and described in Table 2.

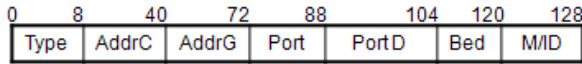


Fig. 5 - Format of cmrmg

Table 2 - Description of cmrmg

Field	Size	Description
Type	8 bits	Type of message that is being sent.
AddrC	32 bits	Multicast address for reception of registration confirmation in group.
AddrG	32 bits	Multicast address of the group.
Port	16 bits	Port of destiny.
Device Port	16 bits	It is used to indicate in which port a device receives messages from its group.
Bed	16 bits	Bed where the device is.

F. Re-indexing Message of nodes (rmn)

The re-indexing messages of nodes (rmn) are sent by the service provider to the master node of each group. This message indicates for the master which nodes are "on" in its group. Therefore, there won't be a token passage for the nodes that are not active. This contributes to improving the use factor in the network. The rmn messages have the LN field (nodes list) of 128 bits that indicates which devices are on or off. The bit index indicates the device and its value

indicates the status of the node. The bits equals to '0' indicate inactive nodes and bits with value '1' indicate active nodes. The Figure 6 illustrates the format of rmn and the Table 3 describes the fields.

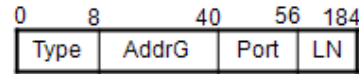


Fig. 6 - Format of rmn

Table 3 - Description of rmn

Field	Size	Description
Type	8 bits	Type of message that is being sent.
Multicast Address	32 bits	Multicast Address of the group.
Port	16 bits	Port of destiny.
LN	128 bits	It contains information regarding the nodes that are no more part of the group (bed).

G. Data message (dm)

The data messages (dm) are sent in synchronous windows by any device for the multicast group that is enrolled. The nodes which are associated with the port message will process it. An important factor included in the data messages is the temporary redundancy implemented through the PD field (Previous data). This field stores data of previous messages. The format of data message is illustrated in the Figure 7 and described in the Table 4.

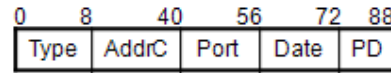


Fig. 7 - Format of dm

Table 4 - Description of dm

Field	Size	Description
Type	8 bits	Type of message that is being sent.
AddrC	32 bits	Multicast address for reception of registration confirmation in group.
Port	16 bits	Port of destiny. This field is according to device type.
Data	16 bits	Data sent to device(s).
PD	16 bits	Data from the previous period.

H. Experimental results

The results verified the periodicity and efficiency of the multicycles in PM-AH. Therefore, we observed the determinism on the following synchronous aspects:

- Instants that master transmits the token;
- Instants of data transmission by slaves.

To accomplish the tests a scenery was created with two groups, each one containing a master and slave. The whole test scenery was built using conventional computers and software developed in Java programming language to emulate the protocol PM-AH. Over this scenery the

execution of the multicycles in parallel on multicast address was considered. The Figure 8 illustrates the test scenery.

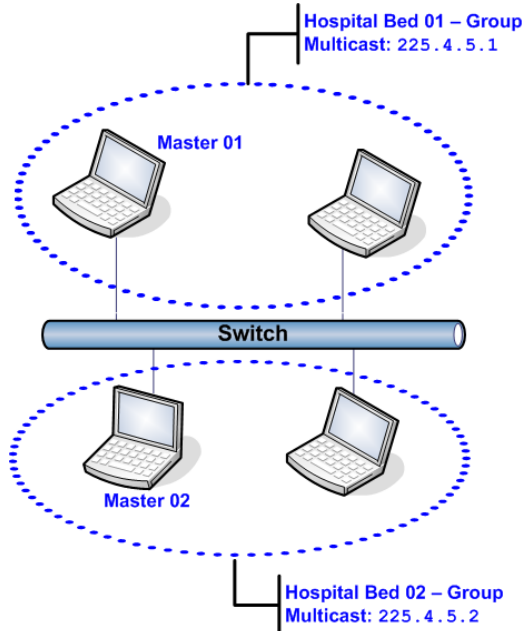


Fig. 8 – Test Scenery

The Figure 8 shows two groups, which are segmented by their respective multicast addresses. Over this environment, 1000 cycles were generated within the period of 100ms. The experiment mentioned to have cycles generated in parallel (multicycles), where it is possible to observe the determinism and periodicity of PM-AH for the two groups. Four computers were used in this experiment with the following configurations: Processor AMD of 1.8Ghz; 512MB RAM memory; Net Interface 100Mbps and a Switch Ethernet 100Mbps with multicast address support.

From Figure 9, we noticed that PM-AH ensured 100% of synchronism between the tokens passages. Furthermore, the

figure shows a 58 μs delay in the tokens passing. Also, there was no loss on the *mtp* message.

Sampling of Sending Data Messages

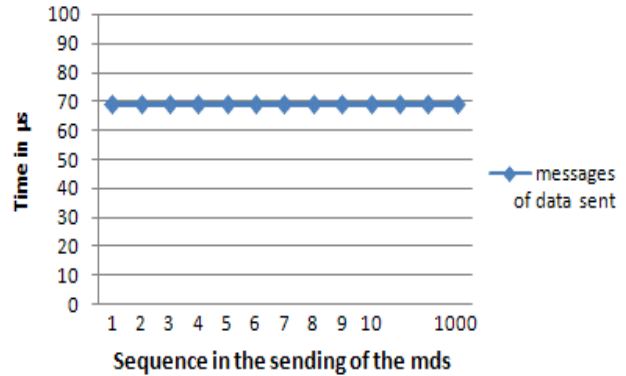


Fig. 10 - Time of messages of data

Table 5 - Analysis of the delay times in the dm

Topics	Value
Standard deviation	22×10^{-4}
Average time	68,58μs
Variance	49×10^{-8}
Average Jitter	23×10^{-4}

The experiment allowed us to accomplish the measurement of the times of transmission of the dm message. The Table 5 shows some analyzed topics.

The Figure 10 reinforces the data presented in the Table 5, showing a constant tendency in the delay of the data messages exchanged among devices in the synchronous windows. This represents an expressive determinism factor

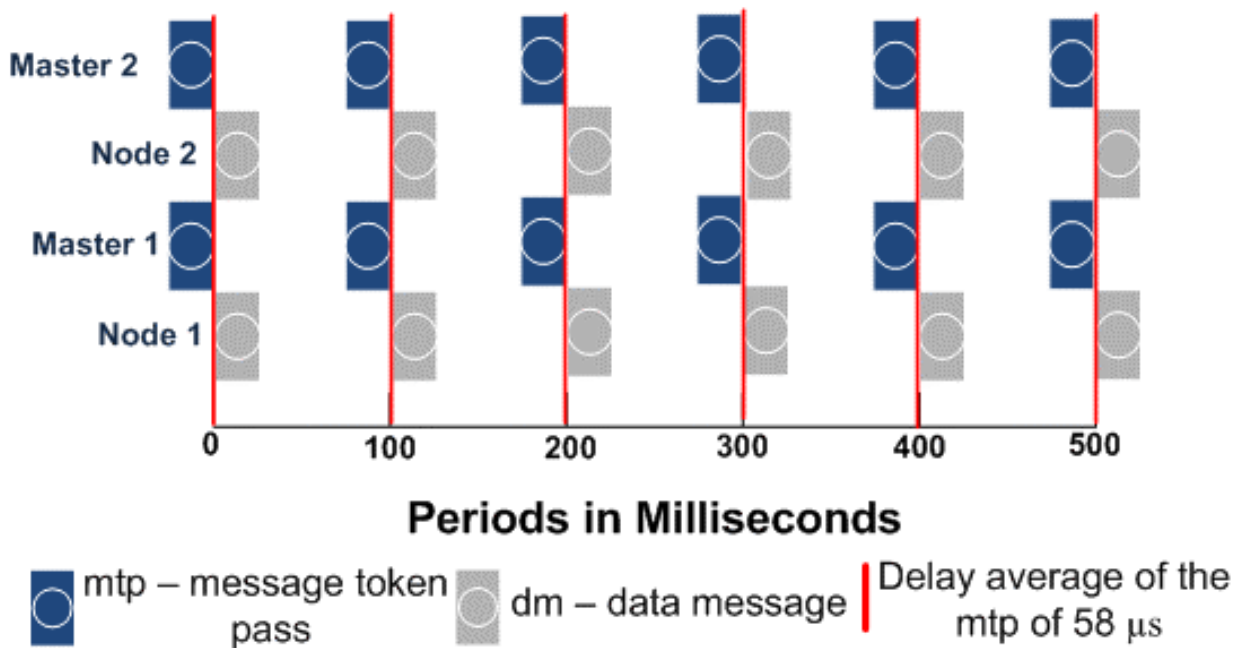


Fig. 9 - Graphic for synchronism

of PM-AH.

IV. CONCLUSION

The PM-AH is a protocol that has been developed by LAHB - Laboratory of Hospital Automation and Bio-Engineering at Federal University of Rio Grande do Norte, which is known for its excellence in the health area. This study is going to be tested and implemented at the Ana Bezerra Hospital, which is considered a hospital that conducts and supports research in healthcare. This work reflects the emerging demands on distributed applications for hospital automation.

The first results motivated us to improve and conduct more tests to show the efficiency of the protocol. The protocol already showed determinism in the network even though it has been based on Ethernet. This is an important feature of our system, since it is going to be applied in a healthcare environment.

As shown, the first results obtained through the protocol are positive, motivating the research of the group in order to reach a model and to implement the embedded protocol.

ACKNOWLEDGMENT

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