MP-HA: Multicycles Protocol for Hospital Automation over Multicast Addressing

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Abstract—This paper presents a Multicycles Protocol for Hospital Automation (MP-HA) that works over multicast addressing and uses a Master-Slave architecture. The protocol creates a segmented logical network based on multicast addressing associated to 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 parallel cycles which is called multicycles.

I. INTRODUCTION

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

In this context, the hardware and software features have to be over all nodes and not over only 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], proposed patient’s tracking systems.

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

In this context, the Ethernet for industrial automation needs protocols that ensure determinism and reliability. In the literature, we can find some works that aboard these issues: TDMA (Time Division Multiple Access) of [1], VTPE (Virtual Token-Passing Ethernet) of [3], FTT-Ethernet (Flexible Time-Triggered Ethernet Protocol) of III and h-BEB (high priority Binary Exponential Backoff) [7]. These approaches are efficient in guaranteeing the determinism in the network. Although, they don't present politics of scalability and they present problems regarding the optimization of channel allocation. Such aspects happen when:

- Idle slots are observed in the network (approaches based on TDMA and their variations);
- Existence of long cycles (approaches based on TDMA token pass);
- Rejection of new nodes in the network (approaches based on the node admissions control);
- This technology is deprecated (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.

Differently from the previous works based on Ethernet protocol for industrial automation, the MP-HA works with logical segmentation of network. The process of network logical division is transparent and based on address multicast. The MP-HA works on IP (Internet Protocol) and Ethernet Switch with support to the multicast in level 2.

II. PROTOCOL OVERVIEW

The main motivation for the development of a new protocol was to create a mechanism to solve the problem of
hospital automation. Figure 1 illustrates a model of how this protocol works.

This protocol is based on message group segmentation, that is, it works over IP protocol with multicast addressing. It makes an association between a hospital bed and a multicast group which monitors medical devices (nodes). Each dispositive has only one multicast address. This way, the messages exchanged among nodes do not cross to others groups, increasing the network use factor because it reduces the amount of messages. There is a MP-HA Service Provider (SP) that receives all messages from all nodes. The SP is responsible for the network management and control. For the correct implementation of this strategy, it is necessary to use a switch to make the segmentation at the data link layer level.

The architecture of the protocol is based on multicycles concept and token-passing messages (tpm) between master-slave. Each cycle is divided in two parts: a synchronous and an asynchronous window.

The beginning of a synchronous window is done when the master of a group sends a synchronous window with a (bmsw) message to all nodes in its group. In this window occurs the token-passing under master control, guaranteeing there is no medium dispute. The asynchronous window begins when the master sends an asynchronous window with (bmaw) messages for all nodes in its group. In this window, all nodes may send alarms messages to SP whenever they need, and SP sends control messages to nodes. The main messages protocol MP-HA is described in Table 1.

### Table 1: MP-HA Messages

<table>
<thead>
<tr>
<th>Alias</th>
<th>Length (bits)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>bmsw</td>
<td>100</td>
<td>beginning message of synchronous window</td>
</tr>
<tr>
<td>bmaw</td>
<td>56</td>
<td>beginning message asynchronous window</td>
</tr>
<tr>
<td>rmsmg</td>
<td>96</td>
<td>Request Message of Registration in Multicast Group</td>
</tr>
<tr>
<td>cmrg</td>
<td>128</td>
<td>Confirmation Message of Registration in Multicast Group</td>
</tr>
<tr>
<td>snm</td>
<td>184</td>
<td>sorted node message</td>
</tr>
<tr>
<td>dm</td>
<td>88</td>
<td>data message</td>
</tr>
<tr>
<td>tpm</td>
<td>64</td>
<td>token-passing message</td>
</tr>
</tbody>
</table>

III. ARCHITECTURE OF MP-HA

MP-HA is a protocol that uses the concept of messages groups segmentation, because, it works with IP protocol, relying on multicast addresses. By 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 message sent by a node to bed $n$, will only be received by another node of the same bed and the Service Provider (SP) MP-HA. The service provider is able to receive all messages. An important aspect of MP-HA in the use of the multicast IP address is the increasing of the network use factor, because this strategy promotes a mechanism that makes the messages distribution process more efficient. Thus, it avoids redundancy in the sending process of data due to the adopted strategy in MP-HA joined to the multicast transmissions characteristics.

Figure 2 exhibits the architecture of MP-HA, illustrating an overview of the context described in this section. The windows of synchronous messages are used for transmission of control messages and data. The windows of 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 the nodes of the group. This characteristic contributes to the reduction of the protocol communication cost.

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

MP-HA is based on a master-slave existent structure and on 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 multicycles 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. This occurs due to the use of Ethernet switch multicast. Then, MP-HA allows optimizing of the temporary cycles, because the cycles don't grow according to the amount of...
nodes that are part of the network, but, according to the amount of nodes enrolled in each group (hospital bed).

The logical segmentation based on multicast IP address develops smaller cycles, allowing faster message sending in each group. The duration time of the 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, guaranteeing the synchronization of the network nodes and consequently its respective periods for messages transmission.

IV. ELEMENTS OF MP-HA

The MP-HA 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 listens to all messages in the network. The SP saves the messages and supplies data for the supervisory, allowing the hospital staff to monitor the patients. In MP-HA, the initiation and the formation of the multicast groups are accomplished through association tables. In the Figure 3, it is possible to verify the structure of the storage table in MP-HA. Those tables are stored in the SP.

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 a node in which multicast group it should be enrolled before sending their messages of data.

Another important table is Group Table (bed ➔ device) illustrated in the Figure 3, which is dynamically created starting from the registration of the nodes in the networks.

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

B. Master

The group master in MP-HA is indicated by the SP. The master definition processing starts when the node sends a request message of registration in multicast group (rmmrg). After the message is sent to SP, it 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 one. The node master 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 token pass message (tpm) that indicates which device will have the ownership of the physical medium. So, the device will send a data message (dm) for its multicast group and SP.

The coordination of the network 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 network;
• It optimizes the cycle times, since the slot of idle time won’t exist in the network.

C. Temporal cycle: Synchronous and Asynchronous Window

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

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

\[
T_{sw} = \left( \sum_{i=1}^{q} T_{p_i} + T_v \right), \quad T_p = \left( \frac{d}{t_s} \right), \quad T_v = \frac{L}{R} \quad (1)
\]

Where,

\( q \) = Number of nodes in the group (considering the master node);
\( T_p \) = Time of message propagation in the physical channel;
\( d \) = physical distance;
\( t_s \) = Transmission speed of physical medium;
\( T_v \) = Time of message transmission according to range of network transmission (10Mb/100Mb/1Gb);
\( L \) = Message length;
\( R \) = Transmission Rate.
V. EXPERIMENTAL RESULT

The results verified the periodicity and efficiency of the multicyles in the MP-HA. Therefore, we observed the determinism on the following synchronous aspects:

- Instants that the master transmits the token;
- Instants of data transmission by slaves.
- To accomplish the tests there was created a scenario with two groups, each one containing a master and a slave.

The whole test scenario was built using conventional computers and software developed in Java programming language to simulate the MP-HA protocol. Over this scenario there was considered the execution of the multicyles in parallel on multicast address.

Over environment test, 1000 cycles were generated with period of 100ms. The experiment mentioned had cycles generated in parallel (multicyles), where it is possible to observe the determinism and periodicity of the MP-HA for both groups. Four computers were used in this experiment with the following configurations: Processor AMD of 1.8Ghz; 512MB RAM memory; Network Interface 100Mbps and a Switch Ethernet 100Mbps with multicast address support.

From Figure 4, we noticed that the MP-HA ensured 100% on message delivering synchronism and on the token-passing. Furthermore, the figure shows an average delay of 58 µs with the token-passing and no tmp was lost.

The experiment allowed us to accomplish the measurement of the transmission times of the dm message. Table 2 shows some analyzed topics.

<table>
<thead>
<tr>
<th>Topics</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard deviation</td>
<td>22x10^-4</td>
</tr>
<tr>
<td>Average time</td>
<td>68.58µs</td>
</tr>
<tr>
<td>Variance</td>
<td>49x10^-8</td>
</tr>
<tr>
<td>Average Jitter</td>
<td>23x10^-4</td>
</tr>
</tbody>
</table>

Table 2 - Analysis of the delay times in the dm message

![Fig. 4 - Graphic for synchronism](image)

The data presented in the Table 2, showing a constant tendency in the delay on the data messages exchanged among devices in the synchronous windows. This represents an expressive determinism factor of MP-HA. This occurred because the MP-HA runs over Ethernet switch multicast.

VI. CONCLUSION

MP-HA is a protocol that has being developed by Laboratory of Hospital Automation and Bio-Engineering (LAHB) at Federal University of Rio Grande do Norte (UFRN). This study is going to be tested and implemented at the Ana Bezerra Hospital, which is considered a hospital that conducts and supports researches 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 is based on Ethernet. This is an important feature of our system, since it is going to be applied in a healthcare environment.

As was shown, the first results through the protocol were positive, thus motivating the researches of the group in a way to model and to implement the embedded protocol.

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