ISA Transactions 48 (2009) 228–236

Contents lists available at ScienceDirect

ISA Transactions

journal homepage: www.elsevier.com/locate/isatrans

A computer tool to support in design of industrial Ethernet

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ARTICLE INFO

Article history:
Received 18 September 2008
Received in revised form
14 December 2008
Accepted 14 January 2009
Available online 11 February 2009

Keywords:
Industrial networks
Simulation
Physical layer
Traffic efficiency
Wireless

ABSTRACT

This paper presents a computer tool to support in the project and development of an industrial Ethernet network, verifying the physical layer (cables – resistance and capacitance, scan time, network power supply – POE's concept "Power Over Ethernet" and wireless), and occupation rate (amount of information transmitted to the network versus the controller network scan time). These functions are accomplished without a single physical element installed in the network, using only simulation. The computer tool has a software that presents a detailed vision of the network to the user, besides showing some possible problems in the network, and having an extremely friendly environment.

1. Introduction

Network technologies greatly benefit the industrial automation world. Since the 1980s, the use of fieldbus has helped engineers to build systems with distributed peripheral components, cutting cabling cost, and improving availability and maintenance. Intelligent maintenance and diagnostic information are well known fieldbus advantages [1–3].

In the past few years, the introduction of high bandwidth in networks at the factory floor has accelerated changes in the automation systems, but bandwidth is not the only request for industrial applications. Now, distributed peripheral components can have enough computational power in order to contribute to controlling algorithm execution. Fast networks, such as Ethernet, are suitable to transport information in less time to close control loops [4,5]. Clearly, some improvements to Ethernet standard must be introduced to reach the desired deterministic behavior. A Real-Time Ethernet (RTE) protocol differs from others in the way such improvements will make its performance better; we have several proposals in the literature presenting different real-time domains. The most famous RTE (Real-Time Ethernet) protocols (e.g. PROFINET IO, Ethernet/IP, EtherCAT and Powerlink) will be published in the international family standards IEC61558 and IEC61784-2 [6,7].

These protocols have the mission of sending their data from factory floor level to an industrial hierarchy on a higher level. However, each owned protocol has different characteristics among themselves. It needs to standardize those different fieldbus protocols to generic ones like the TCP/IP (Transport Control Protocol/Internet Protocol) on high levels seen by applications. Therefore, the users will have more means to configure, operate, and check diagnostics amongst levels. This solution guided the idea of a standard to the factory floor level, and at that moment the concept of industrial Ethernet arose. The initial idea was a unique standard, however each manufacturer developed its own protocol and that idea was not completely valid, because there were still specific protocols working with TCP/IP [1,8,5,3].

2. A computer tool for industrial Ethernet standard

Nowadays, it is difficult to foresee the functions and the network operations without having specific equipment. Thus, this paper gives a solution to solve this problem. The solution is a computer tool as the software that was projected to support the user to configure, install and analyze his/her network.

Furthermore, there is an explanation about the functions, the necessity and the main characteristics of the software.

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0019-0578/$ – see front matter
doi:10.1016/j.isatra.2009.01.003

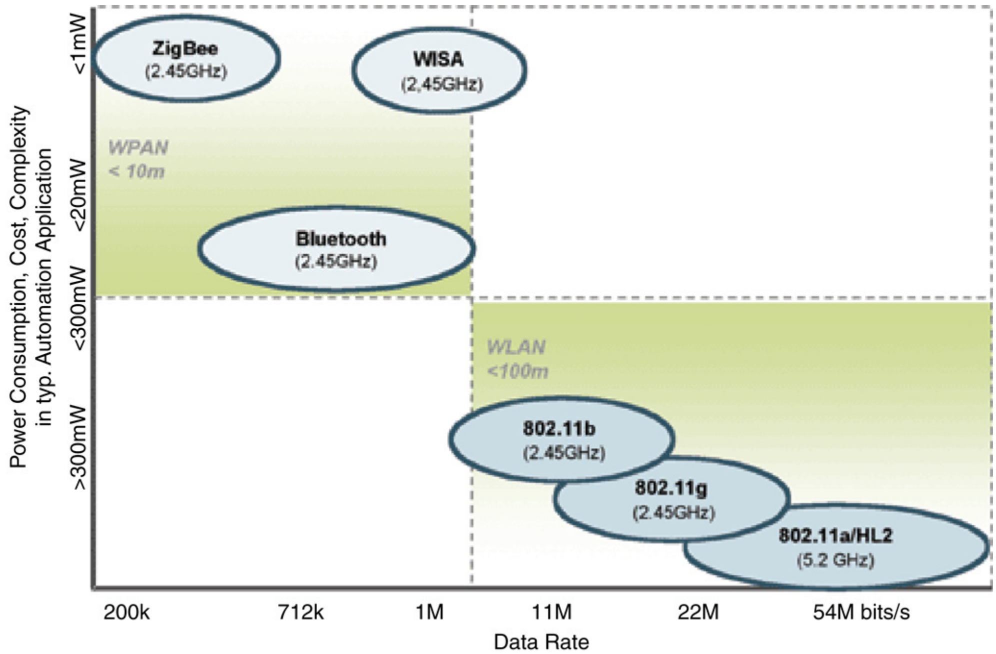


Fig. 1. Wireless standards to industrial Ethernet networks [10–12].

2.1. *Why use this software?*

Nowadays, it is very difficult to simulate network conditions, without having special equipment. The focus of this software is in helping the automation users to choose the best way for the equipment in a network and the type of physical layer (cable or wireless). There are many different protocols and the users have a huge number of parameters they need to know in order to project their network with security.

It is very common for users to choose a technology that serves them better at that moment, and they become dependent on it.

Thus, due to the difficulties and complexities to configuring an industrial network, it is necessary to add visual tools to specify and check the physical and logic network.

The main problems are:

- The physical network project: there are doubts about cable length, maximum cable capacitance and resistance, the connector types and the wireless application;
- The logical network project: these networks have a controller and I/O Modules (Input/Output Modules). Users have access to set up the maximum scan time and bit rate (10 Mbps, 100 Mbps or 1 Gbps) of network. If the users set up a little time and put a lot of I/O modules, their bus traffic will be very huge and there will be data loss. The ideal situation is not having huge bus traffic in a network to avoid loss of data. This problem is very common in factories around the world.

Similarly, it would be useful to have a graphic atmosphere for simulation of the network and to check the parameters. The simulation procedure may avoid future waste of time and upset in the factory start-up. Several physical and logical network problems could be detected during simulation phase.

2.2. *Software functions*

Usually, the problems are not easily noticed in the project phase because of little information and simulation resources.

The purpose of this software is to accomplish an independent network simulation (all of them use TCP/IP architecture), containing the following characteristics:

- Cable size and characteristics of the physical layer (cable length, capacitance, and resistance);
- Possible application from wireless on point to point architecture, where the cable is not possible to be implemented or the costs are very high;
- Bus traffic measurement (it depends on the scan time, numbers of input and output – I/O – messages, and the controller bit rate). The bus traffic measurement is made for UDP (User Datagram Protocol) communication (Ethernet + IP + UDP), because all Industrial Ethernet networks work with the TCP/IP standard [9].

The cable standards are IEEE 802.3u (100BASETX — 100 Mbps) and IEEE (Institute of Electrical and Electronics Engineers) 802.3i (10BASET — 10 Mbps). The specified cable has four pairs (eight wires), 5 UTP categories (with shield) [6,4].

Some main wireless standards are: IEEE802.11b or IEEE802.11a /HL2 for high bit rate, high latency time and high power consumption, and Zigbee, WISA (Wireless Interface Sensor Actuator) or Bluetooth for low bit rate, low latency time and low power consumption. Fig. 1 shows the standards and their characteristics [10–12]. In this work, the user can choose some standards and simulate them.

The connections ought to be made with RJ45 (Registered Jack, number 45) industrial connectors. These connectors are very strong and safe (it usually has a huge International Protection — IP) [4].

Patterns use twisted cable, with a 100 m distance for segment. The software can offer customized solutions for each segment [6,4].

The great automation companies do not usually supply software due to the low financial profit they provide.

It is suggested the software in which the users can visualize their industrial Ethernet network parameters without having any installed element. Fig. 2 shows the main software screen.

The software implementation for industrial Ethernet is based on a graphic platform, where the users have access to several elements and can set up their network in accordance with its needs.

The main software functions are:

- The length cable entry on each segment to obtain the network physical characteristics, such as: voltage on cable, cable resistance and capacitance;

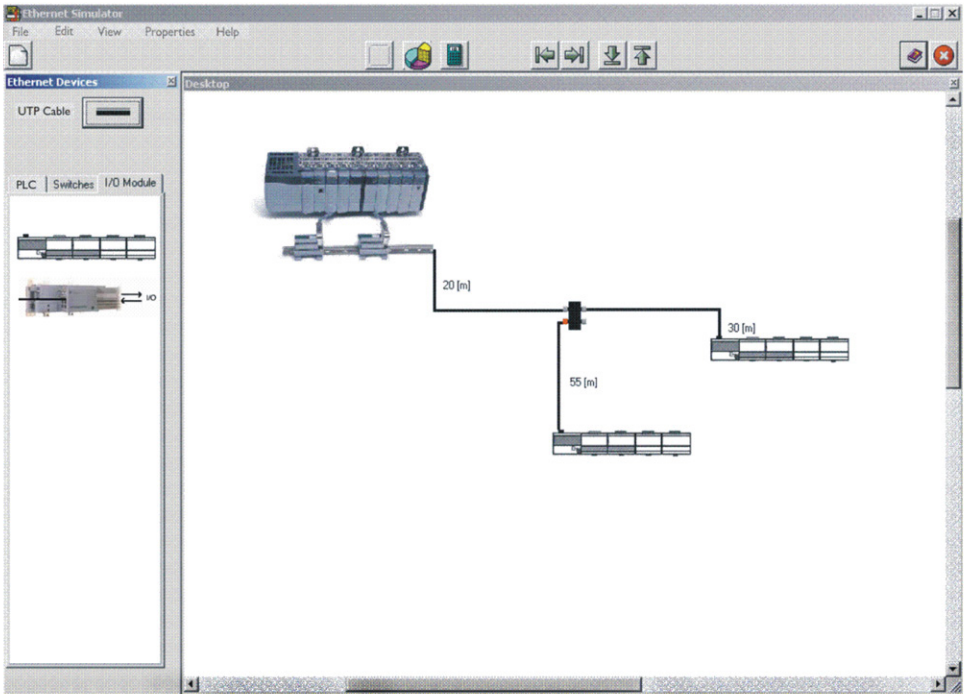


Fig. 2. Software for industrial Ethernet network.

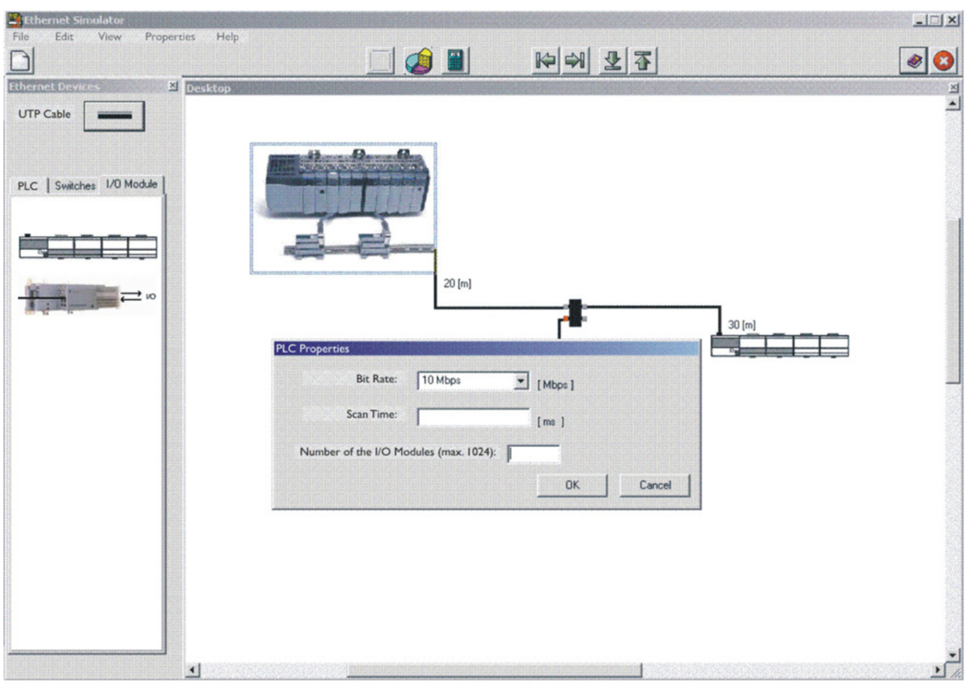


Fig. 3. Controller parameters.

– The scan time entry, the controller bit rate, and the number of I/O module messages for the rate occupation network calculation (bus traffic). This calculation can have a wireless I/O module.

The program language used to develop the software is C++ which is based on Borland Builder [13–16].

Fig. 3 shows the parameters from controller: bit rate (10 Mbps, 100 Mbos or 1 Gbps), scan time (millisecond unit), and the I/O Module numbers.

So, Fig. 4 shows the parameters from an I/O Module: the Input byte number, the Output byte number, and the module address (IP address), the latency time (only to wireless I/O module) and the standard (WISA, Bluetooth or IEEE802.11a).

The bus traffic calculation is made among Ethernet header (26 bytes), IP header (20 bytes) and UDP header (8 bytes). The minimal number of bytes is 72 [17–20]. It considers the controller parameters and the I/O Module parameters, too. The latency time is an extra time needed for wireless I/O module to connect on an industrial switch [10–12].

For each module, it is possible to write the following equations:

$$\text{Input I/O Module time} = \frac{[(\text{among input bytes} + 54) * 8]}{\text{Bit rate}} \tag{1}$$

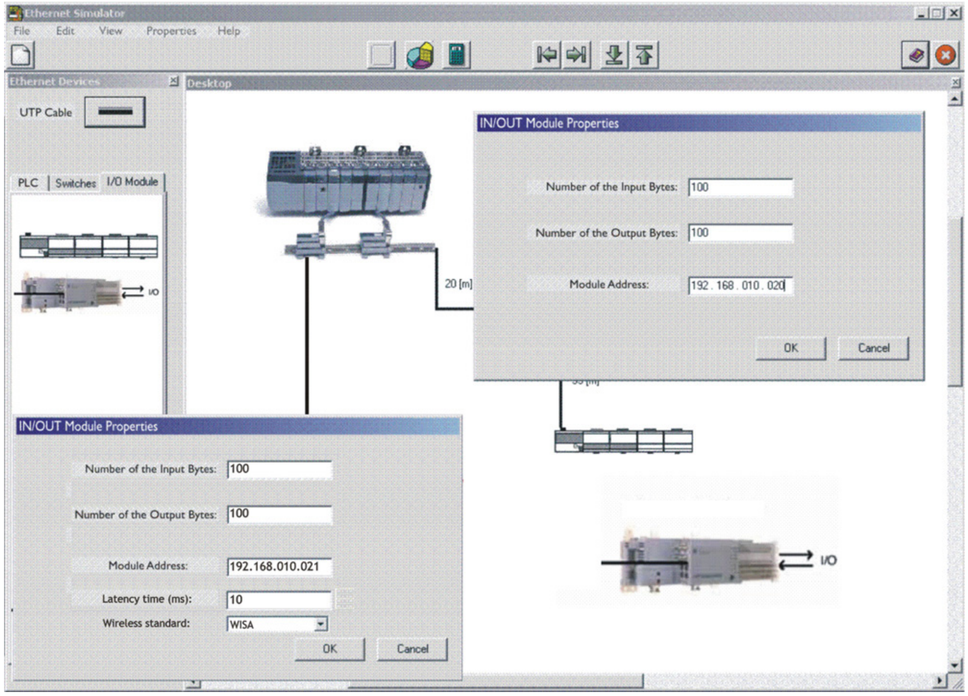


Fig. 4. I/O Module parameters.

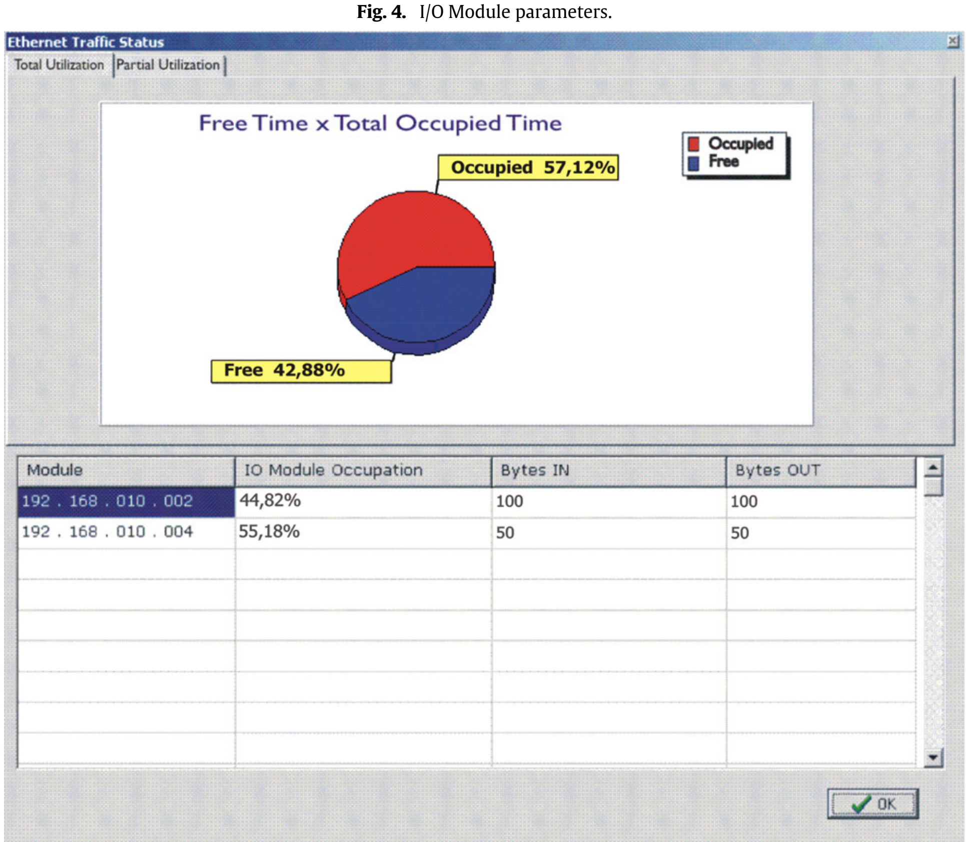


Fig. 5. Bus traffic for each module, 2 I/O modules, 10 Mbps of bit rate, and 1 ms of scan time.

$$\text{Output I/O Module time} = \frac{[(\text{among output bytes} + 54) * 8]}{\text{Bit rate}} \quad (2)$$

$$\begin{aligned}\text{Total occupied time} \; = & \sum[\text{Input I/O Module time} \\ & + \text{Output I/O Module time} \\ & + (\text{I/O Modules among} \\ & \times 9.6 \times 10^{-6})]\end{aligned} \quad (3)$$

$$\text{Free time} = \text{Scan time} - \text{Total occupied time}. \quad (4)$$

Eqs. (1)–(4) were implemented on software to calculate the logical network project and show the free time, and the network used time [6,17,4,18,19]. The 9.6×10^{-6} value is a dead time between controller and I/O Modules [6,17,4]. In Appendix A, there is a UML (Unified Modeling Language) modeling from the software with classes and hierarchies.

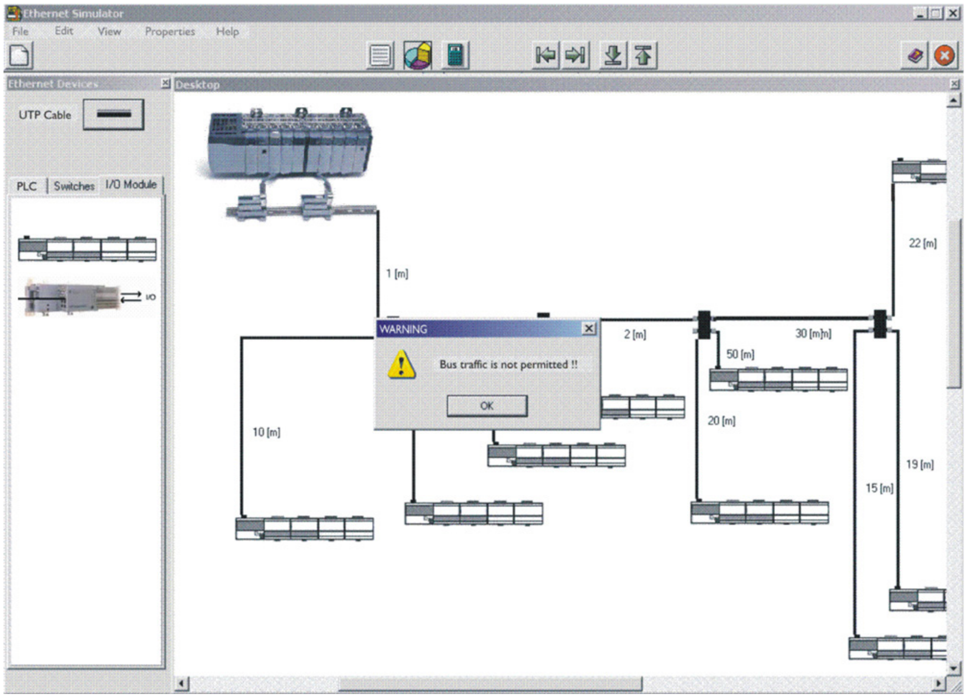


Fig. 6. Result of the bus traffic with 10 Mbps of bit rate, 10 ms of scan time, and 9 I/O modules on network.

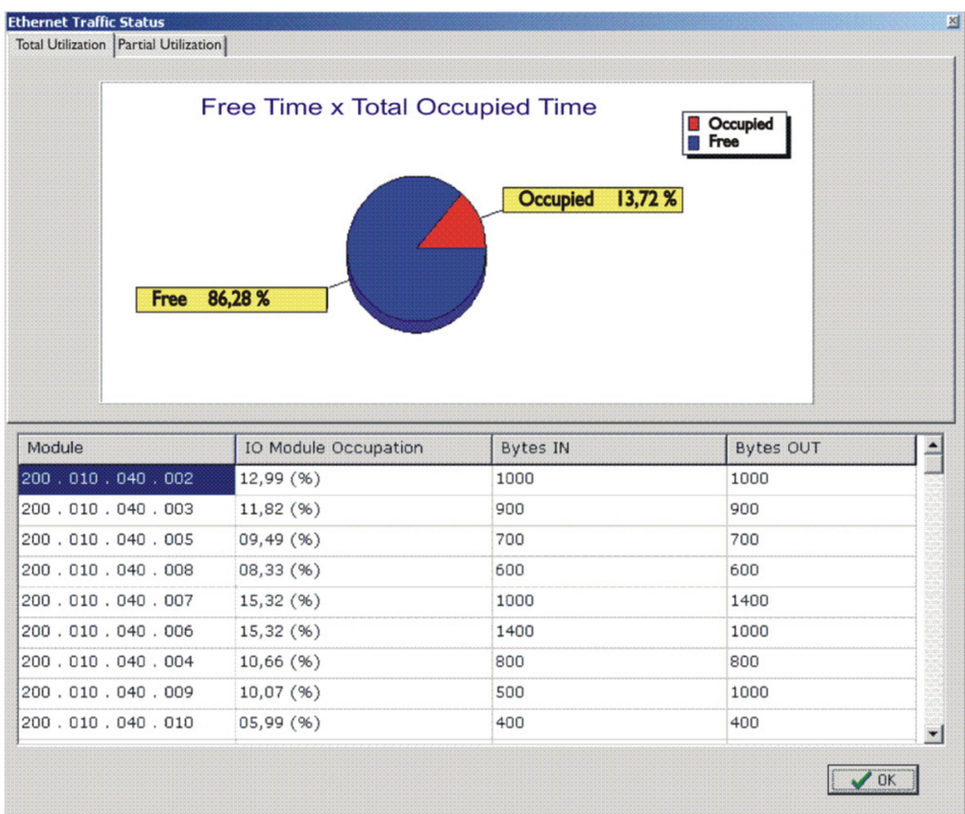


Fig. 7. Result of the bus traffic with 100 Mbps of bit rate, 10 ms of scan time, and 9 I/O modules on network.

These equations are real to the Ethernet physical layer. So, if the physical layer is wireless, the equations are different and it depends on the standard choice. The tool calculates the total time to some wireless standard (WISA, Bluetooth or IEEE802.11a).

2.3. Results and tests

The first simulation is shown in Fig. 5. The controller parameters are: 10 Mbps of bit rate, 1 ms of the scan time, and 2 I/O Modules are supported. The I/O Module parameters are:

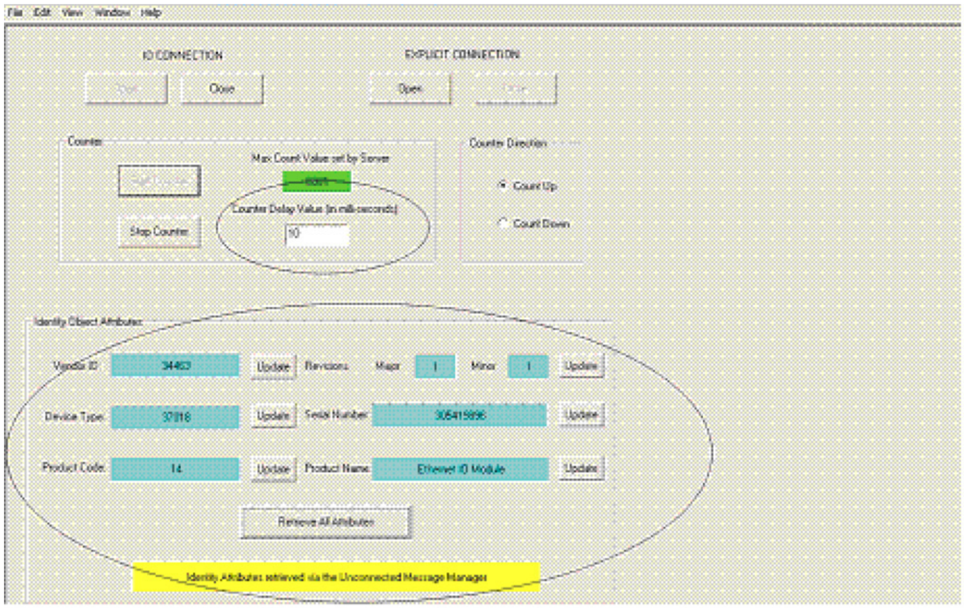


Fig. 8. Controller software from ODVA [6,23].

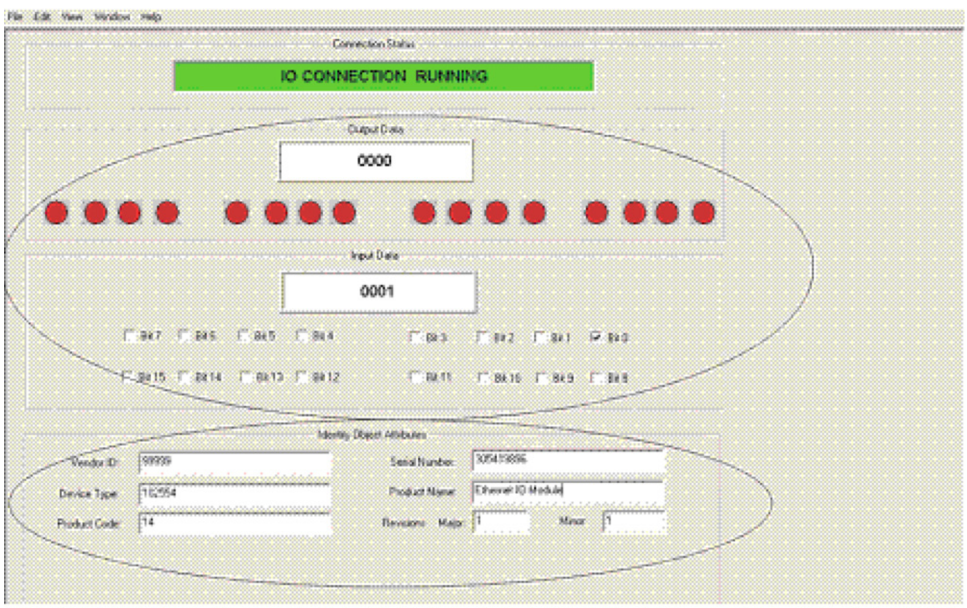


Fig. 9. I/O Module software from ODVA [6,23].

I/O module 192.168.010.002 — 100 Input bytes and 100 Output bytes;

Wireless I/O module 192.168.010.004 — 50 Input bytes, 50 Output bytes, 200 us Latency time and Bluetooth wireless standard.

Result 1: The bus traffic is permitted for this situation (57.12% or 571.2 us of the used time and 42.88% or 428.8 us of the free time). The users can work with network without problems. It is important to see the percentage of each I/O module on used time, 571.2 us (192.168.010.002 = 44.82%, and 192.168.010.004 = 55.18%).

The physical topology is a ring to industrial switch and point to point to wireless. Switches are special and important for network deterministic time [21,22].

This shown traffic is normal and there is no communication problem between controller and I/O modules. A bad traffic is above 90%, according to [6,4].

The second simulation is shown in Fig. 6. The controller parameters are: 10 Mbps of bit rate, 10 ms of the scan time, and 9 I/O Modules are supported. The I/O Module parameters are:

I/O module 200.010.040.002 — 1000 Input bytes and 1000 Output bytes;

I/O module 200.010.040.003 — 900 Input bytes and 900 Output bytes;

I/O module 200.010.040.004 — 800 Input bytes and 800 Output bytes;

I/O module 200.010.040.005 — 700 Input bytes and 700 Output bytes;

I/O module 200.010.040.006 — 1400 Input bytes and 1000 Output bytes;

I/O module 200.010.040.007 — 1000 Input bytes and 1400 Output bytes;

I/O module 200.010.040.008 — 600 Input bytes and 600 Output bytes;

I/O module 200.010.040.009 — 500 Input bytes and 1000 Output bytes;

I/O module 200.010.040.010 — 400 Input bytes and 400 Output bytes;

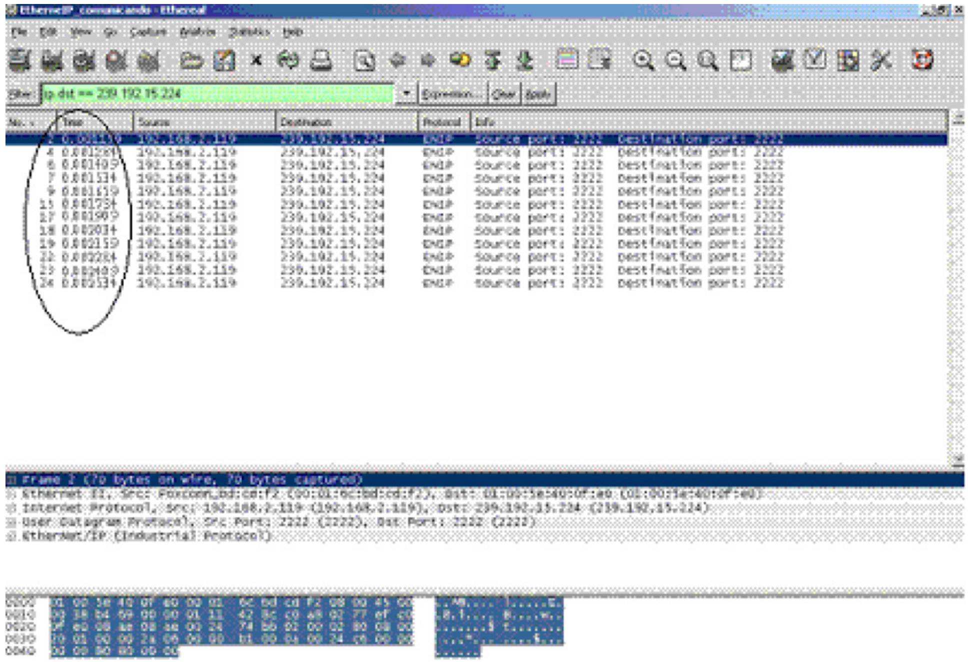


Fig. 10. Ethernet network analyzer [24].

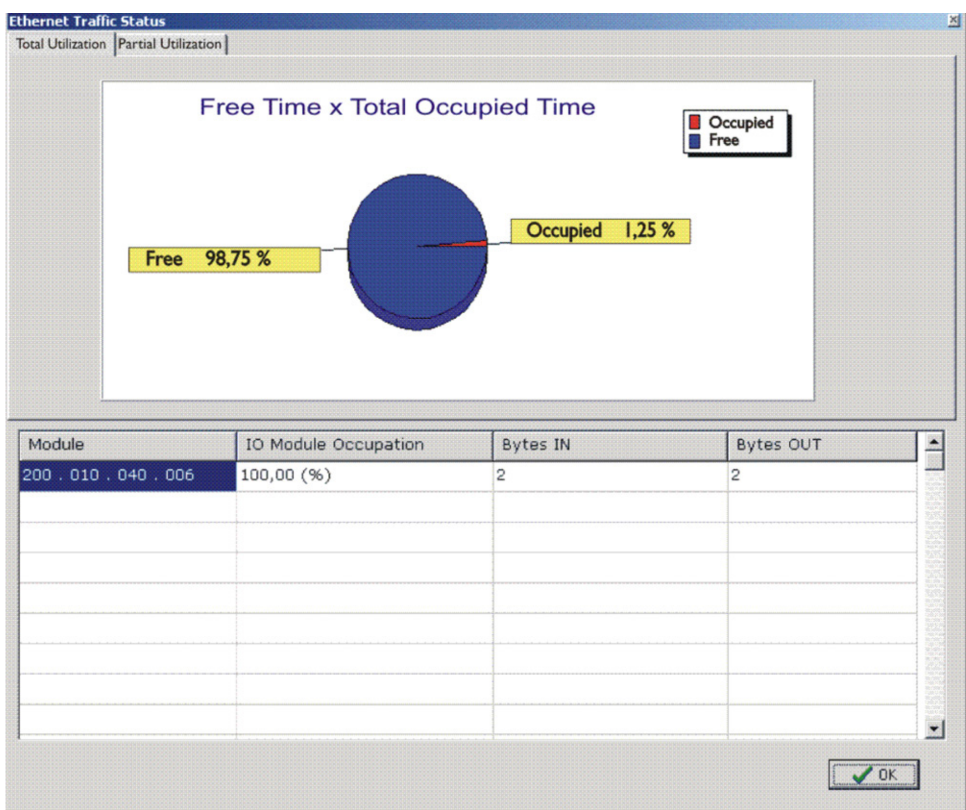
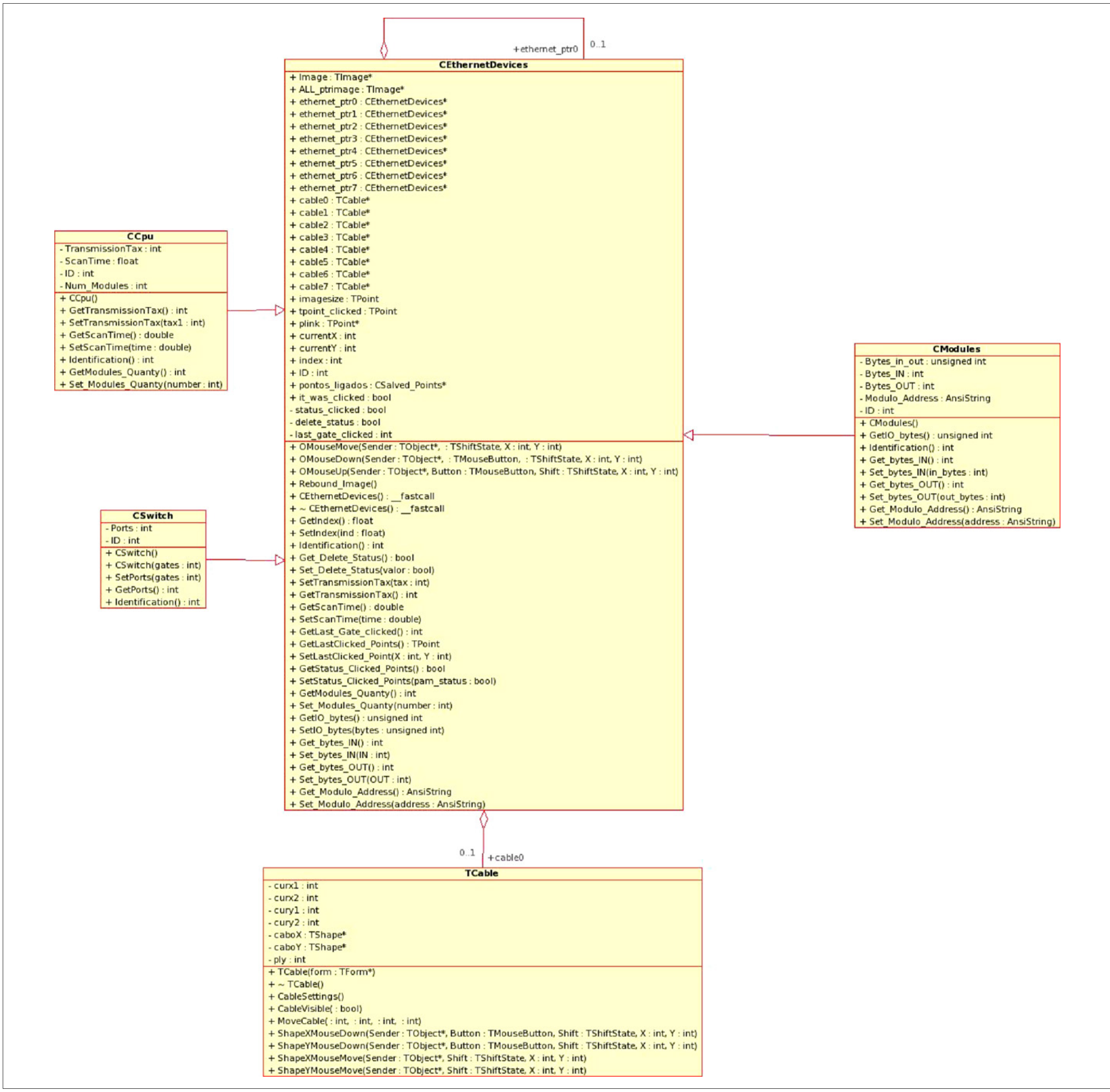


Fig. 11. Result of the bus traffic with 10 Mbps of bit rate, 10 ms of scan time, and 1 I/O module on network.

Result 2: The bus traffic is not permitted for this situation. The total used time is 12.944 ms and it is bigger than the scan time. So, the user cannot work with this network. There will be data loss (bus traffic is bigger than 100%).

Fig. 7 shows one of the possible solutions. The bit rate is changed to 100 Mbps. In this case, the process is not impacted because the other parameters are the same. Now, the bus traffic is permitted for this situation (13.72% or 1.372 ms of the used time and 86.28% or 8.628 ms of the free time). The user can work with this network without problems.

The third simulation is shown below. It is possible to compare this software with a real communication from software from ODVA (Open Device Vendors Association) [6,23] and by utilizing a TCP/IP analyzer tool (Ethereal) [24]. The ODVA software simulates



Box 1.

a controller Ethernet/IP and an I/O module with sensors and actuators (LEDs). The analyzer software is useful to check the frames and the network data. The UDP data are sensor and actuator signals, and TCP data are configuration signals (manufacture number, IP address, controller code and others). The controller sends two output bytes (red LEDs) to the I/O module and receives the two input bytes (switches) in a scan time of 10 min. Figs. 8 and 9 show the controller and the I/O Module from ODVA.

In Fig. 10, it is possible to see that the occupied time is 125 us for this real ODVA case. The Ethernet network analyzer (Ethereal) has shown each cycle with messages, times and addresses. So, the computer tool is validated with the ODVA software and the user can design the project.

Result 3: The bus traffic is permitted for this situation. The total used time is 125 us and it is the same as the ODVA communication. So, the software is equal to normative ODVA.

Fig. 11 shows the simulation parameters to validate the software.

3. Conclusions

The simulations and the software have made it possible for the users to project the system, still in its phase, most of it in the physical layer (distance and cables) as in the network logical layer. Similarly, in the network configuration and installation, many related problems to the project were discussed and simulated, decreasing the time of start-up and the industrial factory costs.

The visualization, the characteristics, and the network simulation elements were formulated in accordance with the industrial market Ethernet networks, as was verified in the simulation results.

Wireless I/O module has a different network bit rate, so the latency time affects in the total time, as seen in the first simulation. Wireless is useful to avoid wiring and to decrease hardware costs in some cases; however the latency time and the standard time must be checked.

The software validation proposed regards real systems (software of ODVA for Ethernet/IP). It could also be verified, turning it into an important tool for the users to simulate and configure the physical and logic layer of their industrial Ethernet network without the need of any linked element physically.

Another contribution to the user is that the software does not arrest to a single network pattern industrial Ethernet, as for example, a very specific application involving Profinet IRT (Isochronous Real Time), for instance. It can be used independently from the network that the user will determine for the operation.

So, it does not matter which industrial Ethernet network type that the user will implement after the simulation.

Appendix

UML documentation (see Box 1).

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