Measurements and Performance Analysis of Industrial Ethernet

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Received on: 6 / 9 / 2005
Accepted on: 26 /6 /2007

Abstract

Industrial Ethernet is a new trend in technology designed to replace the traditional industrial solutions such as point to point and field bus systems. This paper studies Industrial Ethernet performance under different circumstances using the network simulation package(OPNET). Firstly, a validation procedure to the use of OPNET in simulating such networks was made by comparing OPNET performance with practical experiments once and then with analytical models results. Then OPNET was used to study the effect of different parameters on the real time performance of the network. It was found that some parameters like (packet length, number of nodes and packet production rate) have minor effect on the network performance, while the others (packets processing rate and FTP traffic transferred to an industrial node) could affect seriously on the network behavior.

Keywords: Industrial Ethernet , OPNET , Field bus , TCP/IP

الخلاصة

شبكة أثرنيت الصناعية عبارة عن توجه تقني جديد صممت لتكون بديلا عن الحلول الصناعية التقليدية مثل الربط النقطي أو أنظمة ممر المجال. يتناول هذا البحث دراسة خواص شبكة أثرنيت الصناعية تحت ظروف مختلفة و باستخدام حزمة المحاكاة البرمجية (OPNET). في البداية تم التأكد من قابلية الحزمة (OPNET) لمحاكاة شبكات من هذا النوع وذلك بمقارنة نتائجه مع نتائج تجارب عملية مرة و نتائج نماذج رياضية مرة ثانية. بعد ذلك تم استخدام (OPNET) لدراسة تأثير العوامل المختلفة على خصائص الزمن الحقيقي للشبكة حيث وُجد أن بعض العوامل مثل (طول الحزمة , عدد العقد و معدل إنتاج الحزم) لها تأثير قليل على الخصائص بينما البعض الآخر (قابلية معالجة الحزم و حمل FTP موجه للعقدة الصناعية) يمكن أن يؤثر بشكل كبير على أداء الشبكة.

1. Introduction

Traditional control systems composed of interconnected controllers, sensors, and actuators have been successfully implemented using a point-to-point architecture. With this type of architecture, system components are directly wired to various controllers. Modern manufacturing systems must be re-configurable in order to be cost-effective and responsive to market changes. A point-to-point architecture is far away from a re-configurability point of view, as it is difficult to interchange components due to lack of a common communication protocol, and difficult to add, delete or re-configure components since levels of interoperability are generally not defined [1].

As an alternative to point-to-point, the field bus network architecture

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offers more efficient re-configurability and reduces installation and maintenance cost due to the decreased wiring. However, implementing a control system over a common-bus network induces inevitable time delays that degrade performance and can even cause instability [1]. In spite of the clear advantages of field bus systems, they still suffer from some drawbacks such as : lack of standardization, high cost , compatibility difficulties, low speed… etc. Many field bus vendors are moving forward to unify their efforts to establish a common network for their industrial solutions. Industrial Ethernet was chosen to be that solution [2].

Industrial Ethernet uses all types of the protocols of traditional Ethernet including the Transport Control Protocol (TCP), the Internet Protocol (IP) and the media access and signaling technologies found in all Ethernet networks. Building on standard Ethernet technologies means that Industrial Ethernet will work transparently with all the standard Ethernet devices found today. Even more importantly, basing Industrial Ethernet on a standard Ethernet technology platform ensures that as the technology evolves, Industrial Ethernet will evolve with it. The groups supporting Industrial Ethernet are working together to write a comprehensive, consistent standard. Work on Industrial Ethernet is being

Dy communication networks, devices, protocols, and application [5, 6]. OPNET was used to simulate different types of computer networks working in different environments. It was shown in many references [7, 8, and 9] that OPNET gives a very precise results compared to practical networks. Another use of OPNET is to simulate the Industrial Ethernet networks [5, 10]. This is done by

performed by multi-vendor participation, includes writing the specification and thorough comprehensive testing at certified test labs [3].

2. TCP/IP and UDP/IP Usage in Industrial Ethernet

A de facto protocol standard for network communication is the IETF protocol suite, usually called *Transmission Control Protocol/Internet Protocol* (TCP/IP). This suite contains two transport protocols: *Transmission Control Protocol* (TCP) and *User datagram protocol* (UDP). The main differences are that TCP is slow, reliable, and connection-oriented whereas UDP is fast, unreliable, and connectionless. In the case of high-speed measurement data, TCP is less useful due to the protocol overhead involved. Therefore, UDP was chosen as the measurement data real-time protocol. This turns out to be more than satisfactory, since measurement values are sampled at a very high rate. Therefore, if a data set is lost, another set will be coming along shortly [4].

3. Validation of OPNET suitability to simulate industrial Ethernet

The research tool used in this paper was OPNET (**OP**timized **Net**works). It is an advanced package that allows the user to design and stu

using the general blocks of OPNET and feeding them with the important parameters of industrial protocols to simulate the behavior of such networks. However , no validation were made to test the suitability of using OPNET in such area. In this paper, a research, design, analysis and behavior of industrial Ethernet using OPNET software has been accurately explored. This has been done by first comparing the results obtained from running the simulation with practical results, then with that of the analytical model. The details of this work are shown in the next sections.

3.1 Actual Experimental Evaluation

The best method to show the correctness of a simulation model is to compare its output results with that of a similar practical network. This has been done here by building an OPNET simulation model having the same working conditions of the real network. The practical network used is shown in Figure (1).

It consists of the following components:

1. Test equipment: A standard (Intel P4) personal computer was used to collect (and then analyze) the different statistical data of the network. This was achieved by installing a network analyzer package on the computer. The package used was (Open extra Ethereal Network Analyzer) [11].
2. Ethernet Switch: Standard Fast Ethernet, 8 port, store and forward switch following IEEE802.3 standard's specification [12].
3. Device under test: The closest (available) approach to an industrial node was the (TDS 3032 B) oscilloscope from Tektronics [13]. It has the following features:

- 4 channels, 300MHz bandwidth.
- It can be used for remote measurements through a (10 Base T) built in Ethernet port.
- It makes use of (TCP/IP) as the transmission control protocol to transfer the data of the measured signal.

The test procedure presented in [14] was adopted and it can be summarized as follows:

1. The user initiates the measurement process by giving a *"monitor_wave_ form"* command to the oscilloscope. The measurement software package used was (Wave Star)[13].
2. The command is converted to a packet (after entering the TCP/IP stack and then Ethernet medium access layer) then sent out to the network toward the oscilloscope.
3. The packet travels through the network until reaching the switch which stores it temporarily then forwards it to the oscilloscope.
4. When the packet reaches the oscilloscope, the headers removal process (at different oscilloscope communication layers) begin to extract the data contained in it (i.e., the command). On receiving the command, the oscilloscope begins to take samples from the input signal, converts them to digital form, puts them in a packet and sends them to the computer.
5. The data packet when reaches the computer, (after passing through the store & forward switch) it extracts the measured wave form and then display it on the screen.
6. to monitor the waveform continuously, the computer automatically sends another measure command and the above procedure is repeated again.

Some of the network experimental results are shown in table (1). The experiment was ran for (24.79 Sec.) and it was found that packet production rate from the oscilloscope was (44 packet/Sec.) with the packets length distribution as listed in the table. Figure(2) shows the change in the oscilloscope latency over the time.

Oscilloscope latency is defined as the time between giving a command to the oscilloscope until receiving a response from it. The statistical results shown in Figure(2) represent the usual behavior of (TCP/IP) protocols stack and they agrees with TCP/IP behavior presented in many references[8,15].It is worthwhile to mention that the shown results assure the difficulties of using (TCP/IP) in real time control applications.

Measurement's Results

3.2 OPNET Evaluation

In order to investigate the ability of OPNET to simulate the behavior of industrial nodes, an equivalent network to the one shown in Figure (1) was built in the OPNET environment (see Figure (3)). It consists of the following components:

1. The test equipment (TE) used in the real network was modeled using **the standard OPNET workstation Model** with its default settings. Also, the Fast Ethernet Switch was simulated using **the standard 8port OPNET switch Model**.
2. The (TDS3032 B) oscilloscope was modeled using a modified **OPNET workstation Model.** The model was fed with the following parameters:

- Packet arrivals follow Poisson distribution with mean inter-arrival time (0.0228 Sec.) (i.e., 44 packet/Sec.)
- Packet length distribution follows uniform distribution between (64,255) Bytes.
- Packet processing rate (3600 Packet/sec.)[13].Packet processing rate reflects the ability of the node to produce and process packets. Packet processing procedures includes the following tasks[10]:

1. The addition and removal of the headers which belong to layers : four (TCP layer), layer three (IP layer) and layer two (Data link layer).This also includes all necessary calculations on different levels, such as check sum calculation (layers 4 & 3), CRC (layer 2) and all other activities relating to the packet creation procedure.
2. The action and reaction activities made by different protocols on the different layers in the (TCP/IP) stack.

The value of the packet processing rate depends mainly on the speed of the node's processing unit, operating system efficiency and other node's architectural components.

The results obtained from running the simulation model are shown in Figure (4). It is obviously clear that the simulation model gives a very close statistical behavior as compared to that of the real network. The average value and standard deviation of the latency for the practical system were (0.0084 Sec.) and (0.0152), while those for simulated system were (0.0086 Sec.) and (0.0144).

In order to validate the use of Poisson distribution in the simulation model, Chi square test [18-20] was used to check the statistical similarity between the experimental and simulation results. The Chi square formula used on these data is:

$$\mathbf{X^2 = (O-E)^2/E} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where:

O : is the observed frequency of occurrence of items in the experimental results

E : is the expected frequency of occurrence of items in the simulation results

Table (2) lists the distribution of the latency values. The chi square value obtained from equation (1) was (8.98) where as the value obtained from chi square tables for Degree of Freedom (D.F = 5) and (ρ = 0.05) was (11.07). The calculated chi square value is less than the value obtained from the tables, which indicate a (95%) confidence between the experimental and simulation results.

As a conclusion, OPNET proves its ability to emulate the behavior of a real industrial node which makes it an attractive tool to be used in simulating such devices.

4. The Analytical Model

For more validation of OPNET, an analytical model analogous to the simulated network shown in Figure (5) was used. The network consists of 16 sensor, one controller and four actuators [10]. The sensors send packets periodically to the controller where it processes them and then sends proper commands to the actuators. Table (3) lists the detailed parameters of the simulated network.

The value of packet processing rate chosen for the sensors represents the current performance of the commercial industrial nodes [5, 10].On the other hand, the chosen value of the packet processing rate for the controller takes into consideration the expected traffic to and from it(These numbers result from multiplying the number of sources and sinks by the sampling rate plus a safety margin for the unexpected conditions that may occur) .

Both the analytical and simulation models were used to calculate the latency, which can be defined as the time required by a measurement packet to travel by means of the measurement software in the sensor to the application layer in the controller plus the corresponding time for the resulting control packet to travel from the controller back to the actuator.

The analytical equation to calculate the latency of switched Ethernet is [16]:

Latency =(Processing delay at sensor + Ethernet Delay from sensor to controller + Processing delay at controller + Ethernet Delay from controller to actuator + Processing delay at actuator)(2)

Ethernet Delay = Packet transmission time + Switch delay ……….…… (3)

Where:

- Processing delay = (1 / Packet processing rate of the node)
- Packet transmission time = (Packet length / Data Rate)

Switch delay = { Electronic circuits delay + Queuing delay }

According to Ref.[16] the Electronic circuits delay = 45µSec., and from reference [17] :

Queuing delay = ($Ts(2-\rho)/2(1-\rho)$)……………4ne

twork latency is observed when sampling rate is increased(see Figure(8)). This is due to the increase in the number of packets entering the network because the sensors produce more packets that increase the traffic in the network and, hence, the Ethernet Delay.

1. scenario 4 : Variable packet processing rate of the sensors

Packet processing rate reflects the ability of the node to produce and process packets. Low packet processing rate means higher delay in the node's (TCP/IP) stack and, hence, higher latency. This is shown in Figure(9).

5.scenario 5 : Effect of non real time dataIn this scenario, it is assumed that one of the sensors is receiving a 1 Mbyte file(as node's reconfiguration instructions) from a host computer using file transfer protocol(FTP). This file represents a non real time traffic in the network and its effect on the latency is clearly shown in Figure(10).

The increaset in the latency is due to the limited ability of the node (that is subjected to file transfer operation).

The high the increase in the incoming traffic the greater the effect on the node's ability in order to periodically send measurement packets to the controller.

The results of both models(the analytical and the simulated ones) are so close to each other (See figures(6 to 10)). This prove that OPNET software can be used safely.

8. Conclusions

In this paper, industrial Ethernet is introduced as a new technology entering factory automation field. OPNET simulation tool was used to analyze the performance of industrial Ethernet under different circumstances. The main conclusions from this work are:

1. OPNET modeler could efficiently be used to simulate industrial networks.
2. Varying packet length, number of sensors and sensor's sampling rate have minor effects on latency.
3. Packet processing rate of nodes has a great influence on latency and care should be paid to enhance the industrial node's ability in this field.
4. The presence of unmanaged traffic could affect negatively on the whole performance of the industrial network.

References

1. Paul G., Jonathan T., James R. And Dawn M.," The implications of Ethernet as a control network" www.mae.cornell.edu/SEC/Otanez/Publications/otanez_implications_2002.pdf , 2002.
2. F.L. Lian. Analysis, Design, Modeling, and Control of Networked Control Systems. PhD thesis, University of Michigan, May 2001.
3.Technical report ,"Industrial Ethernet: A Control Engineer's Guide". www.cisco.com/application/pdf/en/us/guest/products/ps628/c1244/cdccont_0900aecd8013313e.pdf ,2000.
4.Ramez M . , Hany M. , Hassanein H. and Shawki Z., "Performance of Fast and Gigabit Ethernet in networked control systems", www.cs.aucegypt.edu/~opnet , 2001
5. Kim A., "OPNET tutorial", www.loria.fr/~akoubaa/OPNET/Files
6.OPNET Official site, http://www.OPNET.com, 1999.
7. Van den Broeck B., Leys P., Potemans J. , Theunis J. , Van Lil E., Van de Capelle A. ,"Validation of Router Models in OPNET", www.esat.kuleuven.be/telemic/networking/opnetwork02_bart.pdf,2002.
8. lucio G.F. , Farrera M.P., Jammeh E. , Fleury M. and Reed M.J., "OPNET modeler and ns-2: Comparing the accuracy of network simulators for packet level analysis using a network testbed", privatewww.essex.ac.uk/~fleum/weas.pdf, 2001.

9. Chang X.," NETWORK SIMULATIONS WITH OPNET",Proceedings of the 1999 Winter Simulation Conference, 1999.
10. Skeie T., Johannessen S., and Brunner C., “Ethernet in Substation Automation,” IEEE Control Syst. Vol. 22, no. 3, June 2002
11. Ethereal protocol Analyzer , www.Ethereal.com
12. Micronet official Site; http://www.micronet.com
13. Tektronics Official Site : http:// www.tektronics.com
14. Gilsinn J.D. ,"Real time I/O performance metrics and tests for industrial ethernet", www.isd.mel.nist.gov/documents/gilsinn/AUTOW-P042.pdf,2003.
15. Hamilton J.A., Deal J.C. and Grobmeier J.R., "Network modeling and simulation with mixed traffic data sources", www.drew-hamilton.com/wmc00/Hamilton_wmc2000_paper.pdf,2000.
16. Loeser J. and Haertig H.,"Low latency hard real time communication over switched Ethernet", Proceedings of the 16th Euromicro Conference on Real-Time Systems (ECRTS 04), Catania, Italy June 2004
17. Stallings W. , “High speed networks”, Prentice Hall, 1998.
18. Lynch S.M.,” Cross tabs and Chi Square Tests”, www.princeton.edu/~slynch/soc301_notes11.pdf,1997.
19. Luis J., “ The Chi Square test : a large Sample Goodness of Fit Test”, rac.alionscience.com/pdf/Chi_Square.pdf,1998.
20. Maben A.F. , “CHI-SQUARE TEST**”,** www.enviroliteracy.org/pdf/materials/1210.pdf,1997.

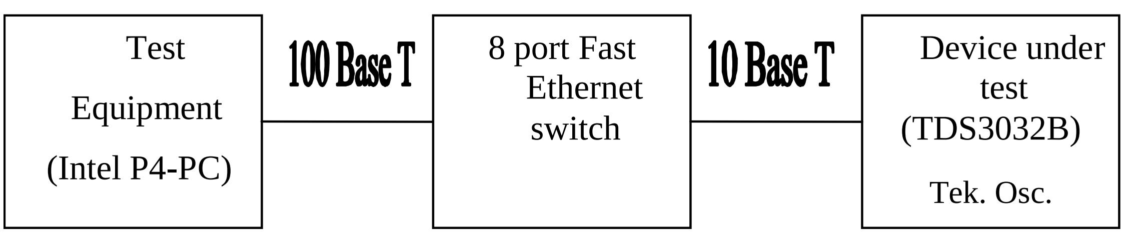
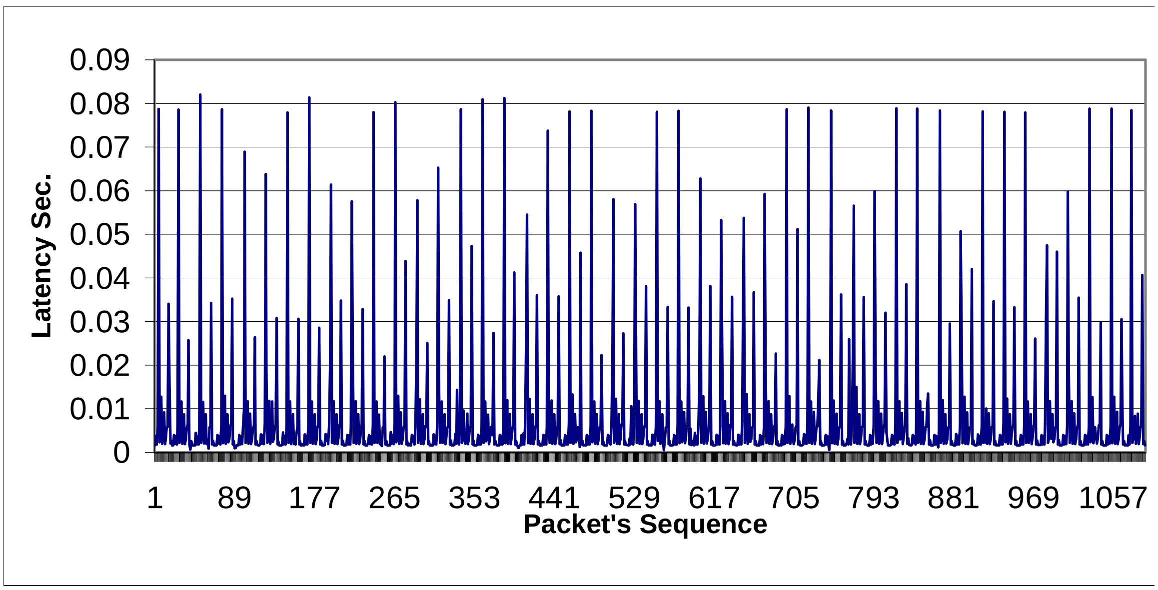


Figure (1): Experimental network

Table (1): Practical Measurement's Results

Experiment Duration	24.79 Sec.
Packet flow rate	44 packet/Sec.
Packet size percentage	(64Byte- 127Byte) = 68.5% (128Byte- 255Byte) = 25% others = 6.5%



Figure(2):Results obtained from the experimental network

Figure(3): Simulated Model Equivalent to the Experimental Setup

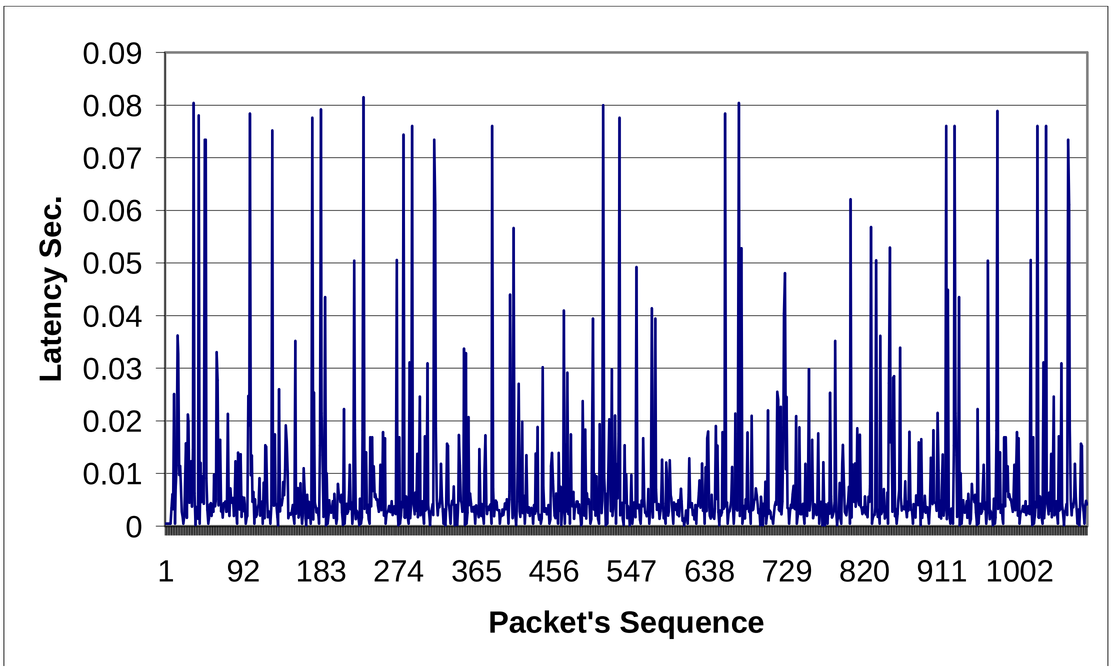


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Figure (4): Results obtained from the simulated network

Table (2):Latency Values Distribution

Latency Values	**Experimental Results Proportion**	**Simulation Results Proportion**
0.0 - 0.01	85.35%	85.18%
0.01 – 0.02	5.31%	5.23%

0.02 – 0.03	2.11%	3.2%
0.03 – 0.04	2.28%	2.55%
0.04 – 0.05	0.73%	0.82%
0.05 – 0.09	4.22%	3.01%

Table (3): Simulated network parameters

Ethernet version	Fast Ethernet (100Mbps)
Sensor's Sampling Rate (packet production rate)	1000 Packet/Sec.
Packet Processing Rate for sensors & Actuators	5000 Packet/Sec.
Packet Processing Rate for controller	30000 Packet/Sec.
Packet length	100Byte
Transmission control protocol	User Datagram Protocol (UDP)
No. of sensors	16
No. of controllers	1
No. of actuators	4