IMPROVING FIELDBUS DESIGN WITH OPNET SIMULATION

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Obiectivele lucrării sunt de a studia rețele industriale reprezentative de tip magistrale de câmp, de a identifica prin simulare factorii semnificativi care influențeaza proiectarea acestora, de a sugera care sunt cei mai importanți din punctul de vedere al eficienței proiectării şi de a demonstra cum pot fi folosiți aceşti factori în proiectare. Pentru simularea rețelelor şi pentru analiza statistică a fluxului informațional s-a folosit Simulatorul de Rețele OPNET. Autorii au elaborate o metodă care permite proiectarea rețelelor de tip magistrală de câmp luând în considerație ca factori semnificativi de influență topologia rețelei (stea sau inel) şi tipul nodului de conectare (hub sau switch).

The aims of this paper are to study the representative industrial network referred to as a fieldbus, to identify the significant factors that affect the network design by network simulation, to suggest which significant factors are more effective when designing the industrial network and to demonstrate how to design the networks by different factors. The network simulator OPNET is used for network simulation and statistical analysis of the information flow. The authors have developed a method to design fieldbus type networks considering significant factors of influence the network topology (ring or star) and the type of the network node (hub or switch).

Keywords: fieldbus, simulation, OPNET, optimal design, statistical analysis

1. Introduction

In industrial operations, it has long been an issue as to how to gather process data, how to analyse it, and how to implement systems to control advanced automatic systems. Over time, many types of control systems have developed; some common contemporary systems are DCS (Distributed Control System), PLC (Programmable Logic Controller) and SCADA (Supervisory Control and Data Acquisition). In the early days, data signals were transmitted between the main devices and the local devices through the use of analog signals such as current (4-20mA) or voltage (1-5V). After analog era, digital signals have been developed instead of analog signals. A significant of amount of data requires

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data lines for control and communication in the process. For this reason, the industrial purposed network has been needed and developed.

The focused domain of this research is industrial digital network, fieldbus. The fieldbus is the serial digital communication network which is able to communicate in real time between devices or central computers in the distributed control and automated system fields. The fieldbus technology developed in the mid 1980's when it was needed to organize the signal transmission system of communication networks which used digital technology. There are also many facilities and instruments in the field of automation systems. An industrial network is a network which is designed for a specific purpose: communication between devices or between devices and a host computer. The variety of industrial controls and automatic devices are connected to the fieldbus network.

To design a more efficient network, it is important to understand which factors will significantly influence the network performance. There are many factors in the fieldbus network. When simulating a network using different factors and analyzing a result, the problems are 1) what is the proper method for designing a network, 2) how to analyze data and 3) how to find the significant factors that influence a network. The purposes of this paper are to study the representative industrial network, fieldbus, to identify the significant factors that influence the network design by network simulation, to predict which significant factors are more effective when designing industrial networks and to demonstrate how to design the networks by different factors. The paper presents the network simulator, OPNET as method and describes how to design a network and analyze data.

2. Industrial networks characteristics

An Industrial Network is the network for communication between devices or facilities. In [1] the authors review that there are various industrial networks and technologies such as CAN(Controller Area Network), SERCOS, MACRO and Lonworks. They also explain the features of fieldbus such as the speed, maximum number of nodes, arbitration, cable type and primary application. Every fieldbus has individual characteristics and has been designed along with the features of each fieldbus. In the paper [2] the author introduces the multi-level network for CIM (Computer Integrated Manufacturing) and the historical aspects of fieldbus. There are hierarchical network levels such as global area networks, wide area networks, local area networks and field area networks in the automation field. Fieldbus is the field area network that enables a communication device like PLC (Programmable Logic Controller) to communicate in the lowest field level. Therefore, the fieldbus is a basic network of advanced manufacturing automation and distributed control system.

In the beginning of the fieldbus technology, the big advantage was thought of as cost savings due to the reduction in wiring. In fact, it is reported that the expenditure for wiring after adapting the fieldbus can be saved. In addition to the cost savings, the fieldbus also provided enhancements of measurement functions. The fieldbus provides the following benefits ([3],[4],[5]):

i. The fieldbus can save the expenditure of wiring compared with an existing point-to-point communication method by using single transmission media. It is possible to make the field devices share common lines by using a fieldbus which uses the multi-drop method and protocol not the hardwiring, point-to-point method. The multi-drop method provides a cost savings during installation by reducing wiring expenses and also during design by reducing the engineering fee.

ii. Unlike the analog signal, the digital fieldbus signal is not affected by noise or distortion. The digital fieldbus signal does not require the conversion of analog to digital or digital to analog.

iii. The fieldbus can transmit several signals simultaneously by using a common line unlike point to point method which requires several signal lines to transmit signals.

iv. The fieldbus is capable of bidirectional communication between devices. Unidirectional communication devices are limited in not being able to monitor the status of devices or to execute automatic periodic calibration through the network. The bidirectional communication devices provide a cost savings in operation and maintenance by monitoring and calibration automatically through the network.

v. The fieldbus provides the capability to build a system connected to a simple network structure. More complex systems increase the possibility of error generation and cost in maintaining the system. The fieldbus provides a highly responsible system without the burden of expensive or complicated software and hardware interface for communication between devices.

vi. As the demand of the system to change the fieldbus is flexible, so new functions can be added and unused functions can be deleted.

vii. The interoperability and flexibility of a fieldbus that has characteristic of open protocol is superior to other network system.

The basic protocol of the fieldbus is based on the OSI 7 layer reference model, but 4 layers (Presentation, Session, Transportation and Network) of the 7 layers are not used and the layers which the fieldbus use are Application, Data link, Physical and so called 8 layer, User layer. The layers 1, 2, 7 include the role of layers 3, 4, 5, which is defined by IEC 61158 (Fieldbus Standardization). For this reason, the fieldbus protocol supports the real time communication between devices and computers and it makes the system easier and faster to implement. The physical layer has a role as physical media such as cable and conversion to digital signal of analog signal, 4-20mA. The data link layer has a role as mediator between physical layer and application layer. The application layer supports the user layer and converts the data to messages. The user layer connects the local devices and builds control functions [6].

An important feature of the fieldbus is the network topology. There are five fundamental topologies such as mesh, star, tree, bus, and ring, each having individual characteristics, which are properly selected when designing the network [7]. There are combined topologies which contain more than two topologies.

i. Mesh (full connection)

Mesh topology shows the fully connected network between nodes, which has n(n-1)/2 physical line to connect n stations. For example, Fig. 1a shows the network that has 5 nodes and 5(5-1)/2, 10 physical links. A mesh topology has several advantages; each link has only its own data traffic because each node has its own link between nodes. The robust point to point structure guarantees the security and privacy between stations. On the other hand, the disadvantages of mesh topology are complexity and high installation fees because of fully connected structure.

ii. Star

In a star topology, the links are connected between peripheral nodes and central node. Fig. 1b shows the star topology that is linked peripheral stations (nodes 0 to 4) and the central hub (node 5). The nodes are not directly connected to each other. The stations can communicate with each other through only a central device, hub. Due to this structure, a star topology is less expensive than a mesh topology. However, it is not cheaper than other topologies such as tree, bus and ring, because each node requires the link between itself and the central hub.

iii. Tree

The basic structure of a tree topology is a star topology. Fig. 1c shows the tree topology that is linked between star topologies by a hub. A tree topology has characteristics of a star topology. The advantages of a tree topology are that it makes the network range wider by using several hubs (repeaters) and allows the network to group by location or purpose of the network.

iv. Bus

In a bus topology, all nodes are linked on one line. All stations in the bus topology use a common line, called a backbone. The advantages of a bus topology are lower installation fees and easier installation than other topologies. Fig. 1d shows the bus topology that all stations are connected on one line. Disadvantages of a bus topology are difficulty in adding a new device and the effect of severe damage when having the problems with the backbone.

v. Ring

In a ring topology, each node is connected by an adjacent node. Fig. 1e shows the ring topology that is connected by one line. Each node has a role as a repeater. Data flow through the single line that links all nodes.

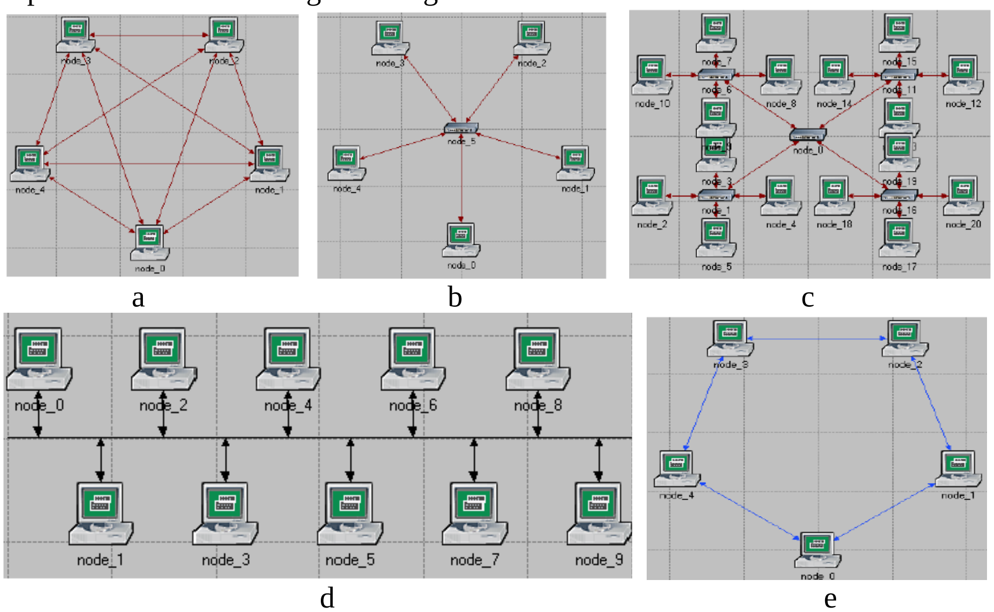


Fig.1. Fieldbus topologies: a) mesh; b) star; c) tree; d)bus; e) ring

As a conclusion on the comparison of the fieldbuses characteristics, Table 1 shows the main features such as data rate, media access method, maximum nodes, topology and maximum segment length for the most encountered industrial fieldbuses.

Table 1

Comparison between fieldbuses

Fieldbuses	Data rate bits/s	Media access method	Maximum nodes	Topology	Max. segment length
Foundation Fieldbus	31.25k	Token passing	240	Bus	2000m
Profibus PA	93.75k	Token passing	32	Bus	1900m
ControlNet	5M	CTDMA	99	Bus, Star, Tree	5000m
WorldFIP	31.25k, 1M and 2.5M	Bus arbiter Access	256	Bus	2000m
Modbus	1M	Token passing	32	Bus	1800m
Interbus	500k	None	255	Ring	12800m
CAN	Up to 1M	CSMA/CD/NDA	64	Bus	40m
Lonworks	300 to 1.2M	Predictive media	32	Bus	1800m
AS-interface	167k	Cyclic polling	32	Bus,Tree	100m

3. Description of the simulation procedure

3.1. General characteristics of the OPNET simulator

A computer network simulator - OPNET - is used for finding factors which influence the network in this paper. OPNET is a network simulation and analysis application software which makes a virtual simulated network environment [8]. It provides various network protocols, topologies and devices which have been used in the real network design. It can design and simulate the network by using network components and easily compare certain networks by multiple scenarios OPNET provides. The strong points of OPNET are:

- It provides an effective GUI (Graphic User Interface) that is easy to understand.
- It includes various types of networks such as wire, wireless, from small size network to wide size network and protocols.
- It provides graphs and spreadsheet data, which allows a designer to analyze the network easily after completing a simulation.
- It has the capability for designing multiple scenarios under one project.

The process of OPNET utilisation has four stages:

i. Network designing
The basic necessities for designing the network are what types of topologies and what types of devices will be used in the network designing. OPNET provides the all kinds of topologies, devices and cables at menu, *Rapid Configuration* and *Object Palette*.

ii. Setting statistics
After modeling the network, the statistic factors that a researcher wants to record in the simulation need to be set. There are three types of statistics in OPNET: *Global Statistics*, *Node Statistics* and *Link Statistic*. These statistic factors enable a researcher to gather the data at every node, link and global statistics. The criteria units in this paper are Traffic Received (packets/sec) and Traffic Sent (packets/sec) in *Global Statistics*.

iii. Run simulation
After designing the network and setting the statistics, the network simulation can be performed. OPNET stores data by the selected statistics.

iv. View result
After running the simulation, all data are seen through *View Result* which includes the data of all scenarios. *View Result* enables a researcher to analyze and compare data between different scenarios.

3.2. The proposed simulation model

It is important to decide which factors influence the network when designing the network. The selected factors considered to be significant to the network in industrial facilities are as below, in table 2.

Table 2

The factors which affect the network design

Factors	- level	+ level
a. The speed rate for communication	1Mbps	2,5Mbps
b. The topology	ring	star
c. The type of the node	hub	switch

The factors above could be investigated by two levels. Each factor has two levels (- level and + level). The criterion that each level has is based on the characteristics that the fieldbus has in table 1 and the levels which are commonly used in the network design. According to the Design of Experiment, the analyzing method which is adopted in this paper is the 2^k full factorial design (k = the number of factors) to analyze the results from this simulation experiment. The 2^k full factorial design has 2^k runs. Table 3 shows the 2^k full factorial array and the number of runs, $2^3 = 8$ in this network simulation experiment.

Table 3

2^3 full factorial array for network simulation

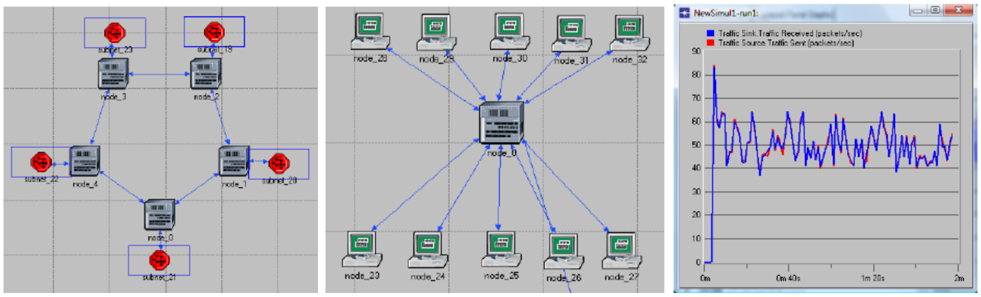
Run order	a	b	c
1	1	-1	1
2	-1	-1	-1
3	1	1	1
4	-1	1	-1
5	1	-1	-1
6	-1	1	1
7	1	1	-1
8	-1	-1	1

Therefore, run 1 represents 2.5Mbps for factor a, ring topology for factor b, switch for factor c, while run 4 represents 1 Mbps for factor a, star topology for factor b, hub for factor c.

4. Experimental results

The object of measuring response for this research is network efficiency, which is measured by difference between sent packets and received packets. The basic method to obtain network efficiency is the ratio of received packets divided by sent packets. Higher ratio indicates better efficiency. The reason that a network loses packets between sender and receiver is caused by transmission impairment (attenuation, distortion or noise).

Fig. 2 shows the details of the first run simulation.



a b c

Fig.2. Simulation results of the first run: a) network configuration; b) subnetwork; c) data trend

Fig. 2a shows the network configuration which has 5 main nodes of ring topology. Each node has sub network which has 10 stations connected by a switch (fig. 2b). The speed rate and the type of node in both main and sub network are 2.5Mbps and switch. The distance between nodes in the main network is designed around 1km. In this experiment, the criterion unit for analyzing and comparing data that are generated in each run is determined as "packets/sec" which indicates the traffic source (traffic sent packets) and traffic sink (traffic received packets) in global statistics. Fig. 2c shows the trend of the traffic source and traffic sink of the first run for 2 minutes.

According to the network simulation experiment for analyzing 3 network design factors using OPNET, 8 received packets of data and 8 sent packets of data were obtained in different network environments. The criterion unit for response is "packets/sec", which is unit for received packets and sent packets at each run. The ratio of received packets/sent packets is used for response, which indicates the efficiency of a simulated network. The ratio of each run is shown in table 4.

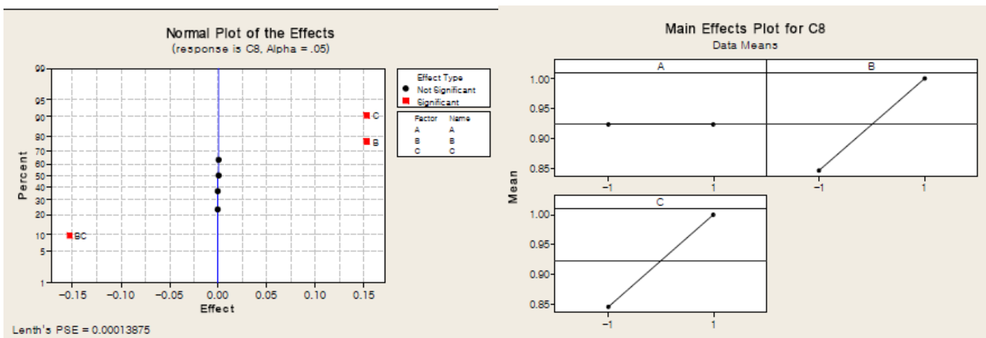
Table 4

Ratio (Received Packets/Sent Packets) for response

	run1	run2	run3	run4	run5	run6	run7	run8
Received Packets	4798.3	3355.8	4849.2	4850	3355.8	4849.2	4851.7	4841.7
Sent Packets	4799.2	4844.2	4850.8	4852.5	4844.2	4850.8	4852.5	4843.3
Ratio	0.9998	0.6928	0.9997	0.9995	0.6928	0.9997	0.9998	0.9997

Fig.3. presents the plots of the analysis realised on the experimental result. The normal plot of the effect estimates from this network simulation experiment is shown in Fig.3a which indicates factor b (the topology) and factor c (the type of hub) as main effects having statistical significance and the largest absolute effect estimates; fig.3a also shows an interaction bc. The other effect, factor a (the speed rate for communication) and other interactions that lie near the line are negligible. Fig. 3b shows the significant main effects such as factor b and c. According to this

network simulation experiment, the significant factors that influence the network design are proven to be the topology and the type of hub, which means that the efficiency of the network that is installed by star topology and switch, is higher than a ring topology and a hub.



a b

Fig. 3. Plots of the effects: a) normal; b) main

5. Conclusions

The purpose of this paper is to find the significant factors that influence a network design by a network simulation. According to this experiment and analysis, main effects such as the topology (ring and star) and the type of hub (hub and switch) and the interaction between topology and hub type are proven to significant factors. Therefore, when designing a network, it will be low efficiency network design if using a ring topology and a hub together. On the other hand, factors such as the speed rate for communication and other interactions are proved to be insignificant in this network simulation.

In addition to the result of this paper, according to the network simulation using OPNET, when designing the network, we can reduce the cost and analyze potential problem before building the network. This paper offers the method to simulate and analyze a network by using network simulator and the design of experiment. The method of design and analysis, presented in this paper, can be adopted any networks that have different factors.

As future work, in addition to the factors that are used in this paper, there are also other factors such as redundancy, protocol, model, to be considered. The network simulation with new factors will provide useful information for network design.

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