Performance Analysis and Experiment of Network Architecture for Distributed Control System

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Abstract: This paper describes the implementation of DCS communication network that provides high bandwidth and reliability. The network for DCS in this paper adopts the Reflective Memory (RM) architecture and Fast Ethernet physical media that have 100Mbps bandwidth. Also, this network uses Ring Enhancement Device (RED) which was invented to reduce the time delay of each node. The DCS network that is introduced in this paper is named as ERCNet(Ethernet based Real-time Control Network). This paper describes the architecture and working algorithms of ERCNet and performs numerical analysis. In addition, the performance of ERCNet is evaluated by experiment using the developed ERCNet network.
Keywords: DCS, ERCNet, Ring Enhancement Device, Network, Reflective Memory

1. INTRODUCTION

As an automatic control technology was started to be used in 1960s and automated equipments that were used in industries were increased and becoming more complicated, industries were getting to use more and more of Distributed Control System(DCS)[1][2]. DCS capacity is getting bigger as processes that industries use became more complicated, and the importance of exchanging and sharing of data between the distributed computers and equipments is increasing. Communication network should have a wide bandwidth to be adapted to developing industry's requirement and it also should be stable considering the characteristics of industry environment. It requires even higher stability in important industries such as a nuclear power plant. In addition, this communication network also should have an easy maintenance and repair ability since it needs to be used more 10 years once it has been installed[3].

One of the major methods being used in data sharing in DCS is Reflected Memory(RM) system. RM system is a network system that the whole network has a specific memory that automatically shares the data when data are updated to a one's own memory area. SCRAMNet(Shared Common RAM Network) of system and RTnet(Real-Time Network) of VMIC(VME Microsystems international Corporation) are the representative products that use RM system in DCS communication network. However, these products are each company's specific commercial use communication network solution that does not use standardized protocol. Therefore, in cases where these communication networks are installed, they should entirely rely on the producing company for maintaining and repairing in high maintenance cost, and the price of the network itself is expensive since they should only use the producing company's own hardware [3][4][5].

This study suggests a DCS communication network with a new RM structure that modified existing RM's shortfalls and can be adapted to a developing industry environment. To modify the shortfalls of the existing RM, ERCNet is realized improving maintenance and repair ability by using standardized structure. This communication network uses physical media of Fast Ethernet that is often being used commercially to modify the existing RM's shortfalls as well as to adapt the system in a constantly developing industrial environment. It also used state driven structure and token passing mechanism to improve its stability. Moreover, RED is designed to reduce time delays in nodes of ring topology communication network.

This study explains a structure and action characteristics of ERCNet and examines a function and action of RED communication network. Mathematical analysis on communication efficiency of the ERCNet is conducted. Using ERCNet, updating times of data to a whole communication network are recorded in numerical expressions. In addition to these, accuracy of analyzed results and efficiency of ERCNet are verified through the experiment using newly developed ERCNet communication network.

This study consists of the followings. In section 2, it explains about a basic structure of ERCNet. It explains a frame structure, data transmitting methods and communication protocol of ERCNet as well as RED. In section 3, it analyzes efficiency of ERCNet, and experiments using test bed of the ERCNet communication network are described in section 4. In section 5, it reaches to a conclusion and explains about succeeding study tasks.

2. BASIC STRUCTURE OF ERCNET

ERCNet has a ring topology and uses token passing mechanism and fast Ethernet physical media. It also uses RED that is newly suggested equipment to improve its efficiency. Structure of ERCNet is Explained in this chapter

2.1 Data type and basic transmitting method of ERCNet

Default global memory size of each node of ERCNet is 512kB. Global memory is a reflected memory method that is a size of the memory that the whole nodes share. The maximum number of nodes in ERCNet is 64 allowing each node to have 8kB memory as a distributed data area. Global memory size of ERCNet node can be expanded by memory upgrade. Although

default global memory of 8kB per each node is given for the whole 512kB global memory, it can be divided into a proper size according to number of whole nodes or data volume that each node contains by setting up the environment at the beginning stage. Data that each node saves in their distributed memory area is divided into a 128 byte data area that is called cell and managed from there. The reason why it makes cell as a basic unit and manages memory area is to make them fast when processing communication frames and to make it easy to manage memory. When ERCNet is begins to operate, it starts to broadcast each part of the global memory to the whole network.

ERCNet operates by each node's broadcasting of allocated data area to other nodes in a regular time period letting other nodes to update that node's data area. This means that it use status driven method unlike the existing RM system usually uses event driven method. The reason why it is designed to use this method is that it considered stability importantly. Each node reads received data and calculates location of the data transmitting the data into an allocated location on its global memory. After transmitting all the data a node supposed to transmit, it sends token frame to the next node. This data transmitting process can be expressed as Figure 1 according to a time sequence.

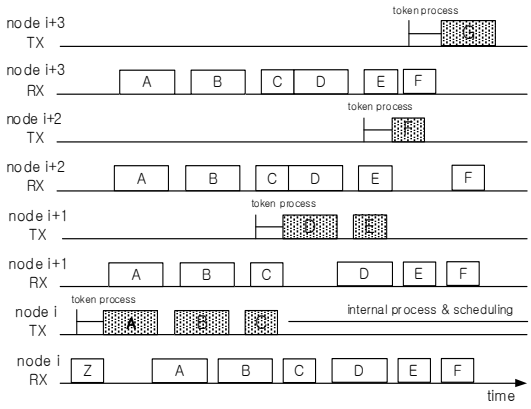

Figure 1. Data transmission process of ERCNet

2.2. ERCNet Communication Protocol

ERCNet only uses physical layer, data-link layer and application layer among the OSI 7 layer. Fast Ethernet transceiver is used as a physical layer, and token passing mechanism is used as a data link layer.

Fast Ethernet is one of the widely used LAN protocols that is verified for its stability and easy maintenance and repair. Physical layer of ERCNet uses physical media of Fast Ethernet. ERCNet uses physical media that follows 100Base-FX standard among the Fast Ethernet standards that uses optical cable and transmits and receives signals. ERCNet uses modified full duplex mode that is one of the Fast Ethernet standards. Although full duplex mode is usually used for connecting two nodes one to one, it connects Tx line of the current node and Rx line of the next node, and Tx line of the previous node to Rx line of the current node. After cabling using this method, each node of ERCNet is connected to each other forming a ring figure.

Data link layer of ERCNet uses token passing mechanism. Token in ERCNet data link has the same meaning as authority to transmit. Only nodes with token can transmit data, and the node passes its token to another node after transmitting allowing the other to transmit data as well. Token circulates among all the nodes in the system using this pattern. In ERCNet, this token is indicated using type/length field in the Fast Ethernet frame format. ERCNet is an industrial use network not connected to other networks it does not need to use type field. Therefore, in ERCNet, this field is used for indicating length of the data frame in case of general data frame. In case of indicating token, the very first bit of this field is set as a token identifier and set it as 1 indicating token frame. Frame structure of ERCNet can be expressed like Figure2.

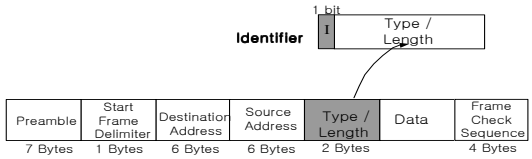

Figure 2. Frame format of ERCNet

2.3. RED (Ring Enhancement Device)

As mentioned before, ERCNet operates as a form of continuous data broadcasting. However ERCNet in ring type topology has a problem that it generates time delays when passing through each node. To solve this problem, specially designed new device is used in ERCNet. It is called RED that transmits analog signal received by Fast Ethernet transceiver to the CPU of node and receives signals through Fast Ethernet transceiver at the same time. This device receives control signal from the CPU and transmits this signal to the CPU and transmitting device when node is in receiving mode. When node receives token and become transmitting mode this device disconnects the connection between receiving and transmitting and transmits data. By using this device, time delay caused by passing through each node when broadcasting that is one of the problem that ring type topology has in ERCNet can be minimized. When re-transmitting the received signal using this device, it does not go through the CPU Processing but switches analog signal directly through Fast Ethernet transceiver. The time taken from passing through nodes in receiving mode is just a time taken from passing through Fast Ethernet transceiver and analog switch.

3. ANALYSIS ON EFFICIENCY OF ERCNET

In this section, data update period of ERCNet is expressed using numerical expression. Parameters for these are as follows.

◇ the number of nodes : N
◇ short term data volume of i^{th} node : Pi
◇ long term data volume of i^{th} node : Qi
◇ data size of one frame : Fd = 1024B
◇ Cell size : Mc =128B
◇ header size(M_{header}) : 16 B
◇ the number of cells in one frame : Ncell = Fd / Mc = 8
◇ distance between of i^{th} node and $i+1^{th}$ node : Li
◇ 1 bit time : Tb
◇ time taken for optical-electric conversion : Toe
◇ time taken for electric-optical conversion : Teo
◇ interframe gap : Tg = 96 Tb
◇ update period in the whole node : Tup
◇ time taken for token transmitting of node : T_{Hi}
◇ time delayed in token recognizing of node : T_{Ath}
◇ time taken in producing data frame of node : T_{Dcr}
◇ time taken in producing token frame of node : T_{Tcr}
◇ time delayed in transmitting token frame of node : T_{Di}

If, *Ns, Nl* represents the number of cells in short term period and long term period that are supposed to be transmitted by i^{th} node in ERCNet respectively, it can be expressed as the followings.

$$N_s = P_i / M_c$$
$$N_l = Q_i / 5 * M_c$$

Using these, the number of short term frame N_{Fs} and long term frame N_{Fl} can be written like these .

$$N_{Fs} = N_s / N_{cell}$$
$$N_{Fl} = N_l / N_{cell}$$

T_{prop} that represents propagation delay due to transmitting lines between each node can be expressed as the following.

$$T_{prop} = \sum_{i=0}^{N} 5 L_i$$

Time taken T_{fs} for transmitting a short term frame is

$$T_{fs} = (N_{Fs} - 1)\{(F_d + M_{header} + M_{CRC})T_b + T_g\}$$

and time taken for transmitting a long term frame is

$$T_{fl} = (N_{Fl} - 1)\{(F_d + M_{header} + M_{CRC})T_b + T_g\}$$

However, the last frame can be smaller than , so the time taken for transmitting the last short term frame is

$$T_{rs} = \{(N_S \bmod N_{cell}) \times M_c + M_{header} + M_{CRC}\}T_b$$

and the time taken for transmitting the last long term frame is

$$T_{rl} = \{(N_l \bmod N_{cell}) \times M_c + M_{header} + M_{CRC}\}T_b$$

The time taken for a node to transmit its communication frame is

$$T_{D_{cell}} = T_{f_s} + T_{r_s} + T_{f_l} + T_{r_l} + T_{oe} + T_{eo} + T_{prop}$$

and update period in the whole network can be expressed as

$$T_{up} = \sum_{i=1}^{N} T_{H_i} = \sum_{i=1}^{N} \{T_{Ath} + (N_{F_s} + N_{F_l})T_{D_{cr}} + T_{D_{cell}} + T_{t_{cr}} + T_{D_i}\}$$

Using the determined data volume and the number of nodes from the results of these equations, update period of ERCNet communication network can be forecasted.

4. EXPERIMENT

Experiment values that can be used for testing the above equations were gained using 4 nodes. The experiment environment and the result from the experiment are represented in the following Table 1.

Substituting these experiment values into the above equations,

Table 1) ERCNet experiment data

N	4	N_{Fl}	0.25
Pi	1920	N_{Ath}	10us
Qi	1152	N_{Dcr}	20.2us
Ns	15	N_{Tcr}	1.1us
Nl	2	N_{Dl}	34us
N_{Fs}	2	N_{Hi}	400us

T_{fs} = (1024+16+32)*8bit*10ns/bit= 85,760ns= 85.76us
T_{rs} = (7*128+16+32)*8bit*10ns/bit= 75,520ns= 75.52us
T_{fl} = (1024+16+32)*8bit*10ns/bit= 85,760ns= 85.76us
T_{rl} = (1*128+16+32)*8bit*10ns/bit= 14,080ns= 14.08us
T_{Dcell} = 85.76us+75.52us+85.76us+14.08us+0.2us+0.15us
= 261.47 us
T_{Hi} = 10us + (2+0.25)(20.2us) + 261.47us + 1.1us + 34us
= 352.02us

T_{Hi} value from the experiment was 400us, and the value

from the equations was 352us that were quite close.

5. CONCLUSION

In a developing industrial environment, efficiency and stability is becoming more and more important factors of design. ERCNet is a communication network that is designed for satisfying these conditions by great efficiency and high stability. ERCNet has a speed of 100Mbps and a token passing mechanism allowing stable data transmission and minimizes time delay in each node using the devices called RED. This study explained the structure of ERCNet, the network that developed for DCS use of the reflective memory method, and proved its accuracy of update period, one of the characteristic of its efficiency, using mathematical analysis and experiment. Users can calculate data update period in ERCNet by data volume and cell size using the analyzed result provided by this study allowing users to predict data update period in DCS system of ERCNet even before installing the system. In the future, It will be more experiments on efficiency of ERCNet by testing more number of nodes.

REFERENCES

[1] Hong-ju Moon, ``Performance analysis and design of a communication network for industrial automation : a case study of the Mini-Map network", Ph. D Thesis, Seoul National University, 1998

[2] Dobrivoje Popovic and Vijay P. Bhatkar, Distributed Computer Control for Industrial Automation, Marcell Dekka Inc., 1990

[3] Jae-Min Lee, Tae-Rim Park, Hyung-Seok Kim, Soo -Young Shin, Jae-Young Choi, Wook-Hyun Kwon, Sung-Woo Lee, Sung-Il Song, "A Communication Network with High Safety, Maintainability, and User Convenience for Digital I&C Systems of Nuclear Power Plants ", 8th IEEE International Conference on Emerging Technologies and Factory Automation, Preceedings, Page(s): 353 -359 , 2001

[4] Moorthy, V.; Jacunski, M.G.; Pillai, M.; Ware, P.P.; Panda, D.K.; Page, T.W., Jr.; Sadayappan, P.; Nagarajan, V.; Daniel, J., "Low-latency message passing on workstation clusters using SCRAMNet", IEEE 13th International and 10th Symposium on Parallel and Distributed Processing, Page(s): 148 -152 , April 1999

[5] Chia Shen, Ichiro Mizunuma, "RT-CRM: Real-Time Channel-Based Reflective Memory", IEEE Transaction on Computers, vol 49, no 11, pp 1202-1214, November 2000

[6] IEEE Standards 802.3, 1998 Clause 3.2.6 Length/Type Field specifications and IEEE 802.1H-1995