Rate-Based Traffic Control of Industrial Networks Employing LonWorks*

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Abstract: Industrial communication networks have attracted much attention in the area of decentralized control systems for factory automation and computer integrated manufacturing. In this paper, we investigate the rate-based traffic control of industrial communication networks employing LonWorks to improve the performance measures of throughput, fairness, and error rates. To this end, we utilize the feedback channel information through the additional network monitoring node and make the overall system closed-loop. We demonstrate the improved performance of the controlled network system by the experimentation upon an implemented lab-scale network system.

1. Introduction

Industrial communication networks (or simply industrial networks) were introduced to effectively address the needs of distributed control systems through the integration of many emerging technologies including information processing, communication networks, and decentralized control. Since the advent of the industrial networks, the concerns have been the inexpensive node cost, compatibility with existing systems, high throughput fair resource management, low transmission delay time, etc. The current industrial networks can be classified into sensorbus, devicebus, and fieldbus. Sensorbus transmits bit-level messages and offers fast communications among bit-level sensors, switches, and actuators; devicebus offers byte-level communications with controllers; fieldbus carries block-level messages and is commonly used in a field. In this paper, we consider industrial network systems employing LonWorks [1]-[3] which is a kind of control networks proposed by Echelon Co. and encompasses all the previous features of industrial networks. In the field of industrial automation, LonWorks becomes regarded as a new promising way to implement the network-based automation systems. However, due to the nondeterministic property of CSMA embedded in the LonTalk protocol of LonWorks [4], there remain several problems to be resolved such as traffic control for the maximal throughput with fair resource allocation. To this end, we investigate the rate-based traffic control [5], [6] of industrial network systems upon LonWorks and illustrate the proposed control algorithm through the experimental results.

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2. Network Configuration

LonWorks is a kind of local operating networks (LONs) [7] developed for the purpose of highly systematic communication of control commands and status signals among nodes in a relatively small group of industrial network systems. The LON aims to communicate via common protocol among low-level devices such as sensors, actuators, and servo-controllers. This is done by connecting each intelligent device node in decentralized peer-to-peer connection. In this way, LonWorks has made it possible for a multitude of applications ranging from hand-held instruments to large process control systems to create affordable networks of intelligent devices that capable of sensing, processing, communicating, and control. The major elements of LonWorks are Neuron chips, LonWorks transceivers, LonTalk protocol, and LNS (LonWorks Network Service) [1]~[4], [8]. In general, industrial networks including LonWorks are operated in open-loop way. Hence, the transmission error rate becomes increased and the throughput becomes decreased as the number of network nodes or the incoming traffic is increased. To resolve these problems, this paper proposes a closed-loop operation by introducing a rate-based traffic controller at each node utilizing the feedback channel information and the incoming data cycle. Especially, we consider a circular queue at each node storing the random input traffic. Fig. 1 illustrates the schematic diagram of the closed-loop network configuration at each node.

3. Control Algorithm

Due to the nondeterministic property of LonTalk protocol embedded in LonWorks-based industrial networks, if congestion occurs at one node then all the other nodes sharing the same channel also undergo some transmission failure. To prevent this kind of congestion and to improve the network performance, we introduce the rate-based traffic control at each node.

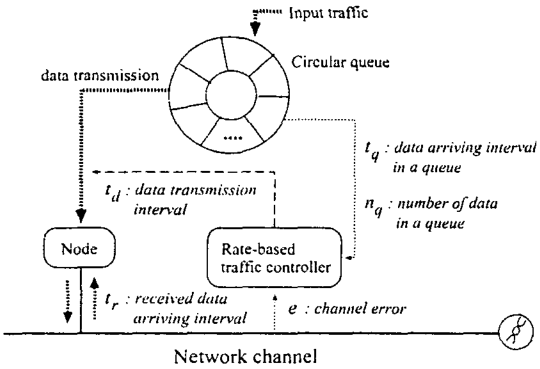

Fig. 1. Schematic diagram of the closed-loop network configuration at each node.

For the quantitative comparison of network performance, we consider the following two performance measures: the measure of throughput J_t and the measure of fairness J_f. We define J_t as the number of successfully transmitted data packets over the transmitted ones. The fairness is usually defined as the ability to provide equal satisfaction to all users [9]. With this concept, we consider the measure of fairness as:

$$J_f = \max_i [(\max_i (I_i - J_{t_i}) - \min_i (I_i - J_{t_i}))/I_i]$$

for $i \in [1, n_d]$, where I_i is the input traffic at ith node, J_{t_i} is the successfully transmitted data traffic at ith node, and n_d is the number of nodes in the network. Assuming equal priority for all the network nodes, the node of heavy input traffic should be allocated more chance to access the network channel in view of fairness. Moreover, the transmission rate should be decreased if the feedback channel errors are increased and be increased proportional to the amount of input traffic stacked in a queue. Therefore, to achieve the maximal throughput in a fair way, the data transmission interval for the nth transmission at the ith node $t_d^i[n]$ to be controlled can be formulated as:

$$t_d^i[n] = k_1 e^i[n-1] + k_2 \sum_{j=1}^{m_q^i[n-1]} t_{q,i}^j[n-1] + k_3 \frac{1}{m_q^i[n-1]}$$

for $n \in [1, \infty)$, where $e^i[n-1]$ is the feedback channel error of the (n - 1)th transmission, $t_{q,i}^j[n-1]$ is the jth data arriving interval in a queue of the ith node until the (n - 1)th transmission, $m_q^i[n-1]$ is the number of data in a queue of the ith node at the (n - 1)th transmission, and k_1, k_2, k_3 are the weighting factors to be determined through an experimentation according to the network configuration. We first measure the arriving interval at the ith node $t_r^i[n-1]$ of the (n - 1)th received data transmitted from the other nodes and then estimate $t_r^i[n]$. Let the estimated value $\tilde{t}_r^i[n]$. Since the occupation of the channel can be expected from this value, the rate-based traffic controller allows to transmit until $t_d^i[n] \geq \tilde{t}_r^i[n]$ if, $t_d^i[n] < \tilde{t}_r^i[n]$ and allows to transmit only once, otherwise. If $t_d^i[n] < \tilde{t}_r^i[n]$ then repeats the previous procedures at the actual data receiving instant.

4. Experimental Results

We investigate the proposed control policy through an experimentation upon a lab-scale network system based on LonWorks. In the experimentation, traffic generators are introduced to simulate the real field channel status. The overall experimental setup is shown in Fig. 2.

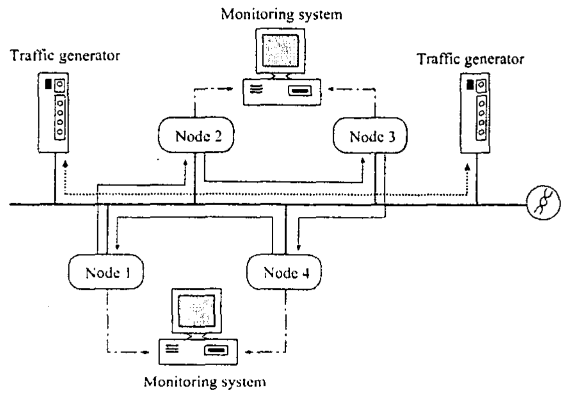

Fig. 2. Overall experimental setup.

The experimentation is conducted without traffic control (open-loop) and with the proposed rate - based traffic control (closed-loop), respectively. The performance measures defined in the previous section are compared for each experimentation. Especially, we count the number of successfully received data packets over the transmission of 1000 data packets of 32-byte unit. J_t from the average value over 5 times repeated experimentation is plotted in Fig. 3 where $n_d = 4$, $k_1 = 0.8$, $k_2 = 1$, and $k_3 = 0.9$. Fig. 3 shows the improvement of J_t via the proposed control policy.

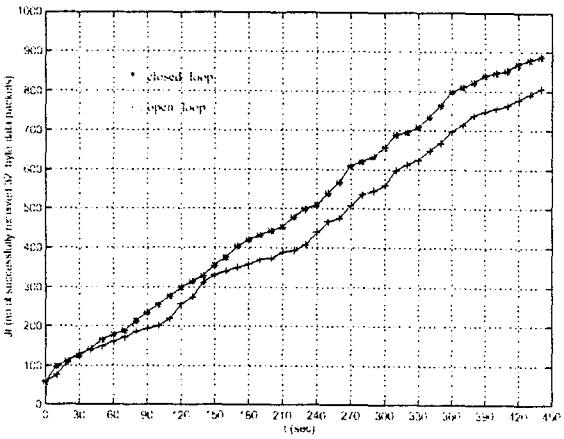

Fig. 3. Comparison of J_t

In addition, the value of J_f, an average error rate ($\bar{e}$), and the average transmission delay ($\bar{\tau}$) are summarized in Table 1 for each experimentation. Table 1 also shows that the value of J_f and e are reduced 76.9% and 41.2% respectively by the proposed control policy without much increase of $\bar{\tau}$ (only 7:1%).

Table 1. Comparison of J_f, $\bar{e}$, and $\bar{\tau}$.

	Open-loop	Closed-loop
J_f	0.16	0.037
$\bar{e}$	19.4	11.4
$\bar{\tau}$	113.2	121.9

5. Conclusions

In this paper, we have studied the rate-based traffic control of industrial networks employing LonWorks to improve their performance with respect to throughput and fairness measures. To this end, we have proposed a control algorithm utilizing the feedback information of network channel errors and the incoming data cycle. The experimental results upon a lab-scale network system based on LonWorks have been provided to demonstrate the proposed control policy.

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